Indian River Inlet Bridge Monitoring Manual

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CHAPTER 1

PURPOSE OF THE MANUAL

1.1 Introduction

The Delaware Department of Transportation (DelDOT) is planning to build a 1,000-foot single rib concrete tied arch bridge over the Indian River Inlet. The bridge, which is shown in Figure 1.1, is being designed by the Figg Engineering Group. The contract for construction of the bridge has not yet been awarded. It will be a monumental structure with an intended service life of over 75 years. The inspection and maintenance of the bridge during that time will require a substantial investment of time and resources. Under the direction of DelDOT, the University of Delaware's Center for Innovative Bridge Engineering (CIBrE) will be installing a long-term structural monitoring system on the bridge during construction and monitoring the bridge from the time of construction through the first bi-annual inspection. The system will enable DelDOT and CIBrE to monitor the bridge during construction to ensure safety, understand the initial bridge condition and use it as a baseline for future evaluations, as well as monitor changes in the bridge condition during its life to aid in ongoing management. Finally, as a result of the significance of the bridge to the surrounding community and its potential as a tourist destination, portions of the monitoring information will be available to the public at an information kiosk.

1.2 Purpose of the Manual

This manual has been written to explain and describe CIBrE's plans to instrument and monitor the bridge. It will detail important information relating to the instrumentation plan in the preliminary, construction, initial condition, and long-term condition stages of the project. The manual is intended to serve as an aid to CIBrE, DelDOT, the contractor, the designer of the bridge (Figg), and the independent reviewer of the bridge (T.Y. Lin). It should be noted that although every effort has been made to make the plans presented within this manual practical, they may need to be modified as unexpected circumstances arise during construction. It is also important to recognize that this manual is not part of the contract documents and should not serve as a replacement for those documents.

Figure 1.1 Proposed Indian River Inlet Bridge (http://www.indianriverinletbridge.com)

CHAPTER 2

SCOPE AND GOALS OF THE PROJECT

2.1 Scope and Goals

In establishing a program to monitor the Indian River Inlet Bridge, CIBrE and DelDOT have focused on creating a system that will not only assist in the construction and maintenance of the bridge but also provide design verification for certain aspects of its behavior. It is the goal of this plan that the data collected from sensors will be used in conjunction with computer models to address the specific design, construction, and maintenance issues associated with the Indian River Inlet Bridge. To this end, the monitoring program has been divided into five stages: preliminary, mechanically stabilized earth wall construction, bridge construction, initial condition, and long-term condition, each with its own unique objectives.

2.1.1 Preliminary Stage

Work done during the preliminary stage of the project will prepare for and assist in completing all future stages. Elements of this stage include creating timelines and procedures, delineating expected results, and obtaining, assembling, and testing instrumentation equipment. It is expected that some unexpected circumstances during the project will lead to modification of the plans set forth in this manual; however, a significant effort has been taken to minimize these events.

2.1.2 Mechanically Stabilized Earth Wall Construction Stage

The main goals of the MSE wall construction stage are to install gauges, set up data acquisition equipment, use the data acquisition equipment to obtain data during construction, compare obtained data with expected results, and issue reports stating and explaining the results.

The purpose of monitoring the MSE walls during the construction stage will be to verify the analytical predictions stress in the reinforcement and the predicted settlement of the MSE walls. Verification will consist of comparing measured data to predicted values. Any major discrepancies between the actual and predicted values will be investigated and reported to DelDOT. At the same time, the data will be made available to the contractor to assist in the construction of the MSE walls and approaches.

2.1.3 Bridge Construction Stage

The main goals of the bridge construction stage are to install gauges, set up data acquisition equipment, use the data acquisition equipment to obtain data during construction, compare obtained data with expected results, and issue reports stating and explaining the results.

The purpose of monitoring during the construction stage will be to verify the analytical predictions of the evolution of stresses during construction and to verify that the temporary stays, support cables, and post-tensioning strands are properly tensioned. Verification will consist of comparing measured erection stresses to those calculated by computer models and determining whether discrepancies occur. Any major discrepancies between the actual and predicted stress values will be investigated and reported to DelDOT. At the same time, the data will be made available to the contractor to assist in the erection of the bridge.

2.1.4 Initial Condition

The initial condition stage will begin as soon as the bridge is completed and may last up to one year. During this time, the main objective will be to establish the baseline behavior of the bridge, so it can be used for design verification and as a reference during the long-term condition stage. Baseline behavior studies will include determining the initial state of stress in the bridge after the construction loads have been applied but before the bridge is opened to traffic. In addition, the baseline response of the bridge to wind, thermal, and traffic loading and the initial settlement of the arch bases will be determined. These measured behaviors will be used to verify the analyses. In each case, collected data will be compared to predicted values to determine whether the computer models used in design accurately predict the actual bridge behavior. Special attention will be paid to aspects of the behavior in which the design team and review team predicted different states of stress, or areas in which stresses are close to the design limits. After this, the baseline responses should be catalogued for future use.

2.1.5 Long-Term Condition

When the initial condition stage ends, the long-term condition stage will begin. The main goals during this stage will be to supplement standard visual inspections, to assist in the maintenance of the bridge, and to determine whether the bridge behavior is changing as it ages. During this time, the condition of the post-tensioning strands, support cables, bearings, and structural members will be assessed by comparing the baseline behavior to the current behavior. The current behavior of the bridge will be determined by examining data from events such as wind, temperature change, and load tests similar to those conducted in the initial condition stage. Changes in the response will be investigated to determine whether they represent significant maintenance issues.

CHAPTER 3

RESPONSIBILITIES

3.1 Responsibilities of Involved Parties

This chapter is intended to identify the specific responsibilities of CIBrE and the contractor for each portion of the IRIB instrumentation program. The chapter will act as a supplement to special provision 763621 University of Delaware Bridge Monitoring Program by fully explaining the special provision and including details which were not available at the time the special provision was written.

3.2 General Responsibilities

This section identifies responsibilities that are relevant to the entire project. The responsibilities listed here apply to all sections in the remainder of this chapter.

3.2.1 CIBrE

- Provide all instrumentation equipment except support cable load cells. Instrumentation equipment shall include gauges, gauge wire, data acquisition systems, communication cables, and the means of attaching these elements to the bridge.
- Install all instrumentation equipment except support cable load cells.

- Provide the contractor with a contact person who will handle all correspondence between the contractor and the University throughout the project.
- Ensure that all University staff who perform work at the bridge construction site or at casting yards have appropriate safety training for the tasks they are performing. This shall be done independently at no cost to the contractor.
- Notify the contractor when alternative portions of the bridge will be instrumented if such action is determined necessary by DelDOT.

3.2.2 Contractor

- Provide the University access to the bridge construction site, the bridge superstructure, temporary construction towers, temporary stays, pile caps, bearings, and fabrication yards for precast members throughout the construction process as detailed in the remainder of this chapter
    - ❖ “Provide access” means that the contractor will provide the means for University staff to physically get to the needed locations to install and read all instruments. It is expected that the contractor will provide the needed lifts, ladders, or other devices to allow this to happen.
    - ❖ The period of time allotted for the University to access a section shall not overlap with the period of time allotted for access to any other section.

- During periods of access provided to the University, appropriate lighting shall be provided by the contractor.

- Move bulky equipment, including but not limited to support cable load cells, to required locations.
- Notify the University contact person at least four weeks prior to work on any item listed in this chapter.
- Allow the University to draw power from onsite generators during selected activities.
- Ensure that gauges, wires, blockouts, data acquisition systems, and any other instrumentation equipment installed by the University are not damaged by the contractor or any subcontractor once they are placed.
- Allow the substitution of alternative segments if it is determined necessary by DelDOT.

3.3 Pile Cap Responsibilities

This portion of the project includes the installation of four chloride penetration monitors (embedded) in the pile cap of the southern arch base.

3.3.1 CIBrE

- Provide and install four chloride penetration monitors and corresponding wires.
- Consult the contractor to determine appropriate blockout location as not to interfere with constructability.
- Provide and install the 8″ x 8″ x 6″ foam blockout.

3.3.2 Contractor

- Provide four hours of access to the southern arch base pile cap before it is cast, but after the entire rebar cage is placed (University staff shall have access and means to reach the entire rebar cage) to allow for the installation of chloride penetration sensors and blockout.
- Upon request from the University approve or suggest the location of 8″ x 8″ x 6″ foam blockout.

3.4 Temporary Construction Tower Responsibilities

This portion of the project involves installing five sets of anemometers on the southern temporary construction towers to take wind speed data during construction. It also involves instrumenting the temporary stays on the southern end of the bridge to allow the forces in the stays to be determined. The instrumentation in this portion of the program will send data to a data logger which will be located at the base of the temporary construction towers. This data logger will be referred to as a *base station* for the remainder of the manual. The specifics of the instrumentation for this portion of the project have not been finalized because they are dependent on the final plans for the temporary construction towers, which are not yet available.

3.4.1 CIBrE

- Review the final design of the temporary towers, which will be provided by the contractor, and devise the specifics of the instrumentation plan.
- Provide the contractor with details of anemometer locations and how they will be installed.

- Provide the contractor with details of the stay monitoring scheme, including which stays will be instrumented and how the instrumentation will be installed (it is anticipated that load cells and/or accelerometers will be used).
- Provide details to the contractor about the base station to be set up at the base of the temporary towers that will log data from anemometers and temporary stay instrumentation.
- Provide and install anemometers, mounting brackets, and wires.
- Provide and install stay instrumentation and wires.
- Provide and install base station to collect data.

3.4.2 Contractor

- Provide the University with the final temporary tower design so that anemometer locations may be determined and stay monitoring may be finalized.
- Provide three hours of access per anemometer set to install five sets of anemometers along with their corresponding wires at various heights on the southern temporary towers.
- Provide two hours of access per stay to allow the University to install instrumentation on the southern temporary tower stays.
- Allow a base station to be set up at the base of the temporary towers that will log data from anemometers and temporary stay instrumentation.
- Allow the University to access the base station as needed to retrieve data; this is anticipated to be a weekly event.

- Provide access to the University to read accelerometers on temporary stays each time they are read (this will require lifts to reach the upper stays).

3.5 Bearing Responsibilities

This portion of the instrumentation program involves installing linear potentiometers (surface mounted) on three of the bearings in the southern arch base and on two bearings for each backspan (two at each abutment).

3.5.1 CIBrE

- Provide and install linear potentiometers, wires, and data acquisition equipment.
- Provide and install data loggers to record data during construction.

3.5.2 Contractor

- Provide 8 hours of access to the bearings in the south arch base immediately upon their installation on the lower portion of the arch base, but before the portion of the arch base above them is cast to allow for the installation of three linear potentiometers and a data logger.
- Provide six hours of access to the bearings at the end of each backspan (abutments) upon completion of each backspan to allow for the installation of two linear potentiometers and one data logger per location.

- Provide four hours of access to the bearings in the south arch base immediately upon unblocking for inspection of instrumentation equipment.
- Provide means for gauge wire to be run from the bearings in the south arch base:
    - ❖ Option One – Install communication conduit with pull wire through arch base to tie beam (as per bridge plans), then provide three hours of access for the installation of gauge wires through the conduit.
    - ❖ Option Two – Install communications conduit with pull wire from arch base directly to UD communications enclosure, then provide three hours access for the installation of gauge wires through the conduit.
- Notify the University as to which option for the wire run from the south arch base will be used; this should be done as soon as practicable once the decision has been made.

3.6 Arch Section Responsibilities

This portion of the instrumentation program involves the installation of weldable foil strain gauges (embedded), vibrating wire strain gauges (embedded), accelerometers (surface mounted), and GPS units (surface mounted) in selected arch segments.

- Arch sections to be instrumented include S-C1U, S-C1D, S-T10U, S-T10D, S-T22U, S-T22D, and S-T36U.

- Sections S-C1U, S-C1D, S-T10U, S-T10D, S-T22U, and S-T22D will each be instrumented with four weldable foil strain gauges, four vibrating wire strain gauges, and one accelerometer.
- Section S-T36U will be instrumented with four weldable foil strain gauges, four vibrating wire strain gauges, one accelerometer, and one GPS unit.

3.6.1 CIBrE

- Provide and install all gauges listed above along with corresponding wires.
- Consult the contractor to determine appropriate blockout locations as not to interfere with constructability.
- Provide and install the 8″ x 8″ x 6″ foam blockout.
- Provide and install data loggers to record data during construction.

3.6.2 Contractor

- Provide access for four hours per section to all arch sections listed above before the section is cast, but after the entire rebar cage is placed (University staff shall have access and means to reach the entire rebar cage) to allow for the installation of embedded gauges and blockouts.
- Upon request from the University approve or suggest the location of 8″ x 8″ x 6″ foam blockouts.
- Ensure that gauges, wires, and blockouts are not damaged once they are placed.

- Provide access to the interior of each section for eight hours per section to all arch sections listed above immediately after it has been cured for installation of accelerometers, GPS units (if applicable), and data logger.

3.7 Support Cable Responsibilities

This portion of the instrumentation program involves the installation of load cells on selected support cables. The load cells are anticipated to be hollow cylinders with a height of roughly 36 inches. The load cell will sit upright in the arch with the support cables running through the center of the cylinder and the anchorage resting on top of the cylinder. Each load cell is expected to weigh several hundred pounds. The load cells must accommodate the pressurized nitrogen system in the support cables and include a gauge for monitoring the pressure of the nitrogen.

- Support cables to be instrumented include 5S, 5D,11S, 11D, and 17S.
- The load cells for these cables will be installed in the arch; corresponding arch sections are S-A9U, S-A9D, S-A21U, S-A21D, and S-A33U.

3.7.1 CIBrE

- Provide and install data loggers to record data during construction.

3.7.2 Contractor

- Purchase support cable load cells that meet the specifications provided in Table 3.1 from a qualified source (two potential suppliers are listed in Table 3.2).

- Install support cable load cells in sections S-A9U, S-A9D, S-A21U, S-A21D, and S-A33U.
- Install the nitrogen sensing system (this shall be done in consultation with the load cell provider).
- Provide access to the University for four hours per load cell once load cells have been placed/installed to allow for installation of one data logger per load cell.

Table 3.1 Load Cell Specifications

Capacity	5,000,000 lb range
Environmental	Splash proof
Temperature range	-30˚ to 150˚ F
Non-linearity	1%FS or better
Dynamic reading capability	
Calibration certification required	
Must accommodate pressurized nitrogen system	
Include a pressure gauge with a range from 0 to 10 psig that reads in 0.1 psi or finer increments and is capable of communicating with data collection equipment	

Table 3.2 List of Potential Load Cell Suppliers

Name	Mailing Address	Website
CTL Group	5400 Old Orchard Road Skokie, IL 60077-1030	www.CTLGroup.com
Honeywell Sensotec	2080 Arlingate Lane Columbus, Ohio, 43228	www.sensotec.com

3.8 Tie Beam/Central Beam Responsibilities

This portion of the instrumentation program involves the installation of weldable foil strain gauges (embedded), vibrating wire strain gauges (embedded), accelerometers (surface mounted), and GPS units (surface mounted) in selected segments of the tie beam and central beam.

- Tie Beam/Central Beam sections to be instrumented include TB-T1U, TB-T1D, TB-T19U, TB-T19D, TB-T37U, CENTRAL BEAM STA. 294+12.500, CENTRAL BEAM STA. 294+78.000, and CENTRAL BEAM STA. 305+22.000.
- Tie Beam/Central Beam sections TB-T1U, TB-T1D, TB-T19U, TB-T19D, TB-T37U, and CENTRAL BEAM STA. 294+12.500 will each be instrumented with four weldable foil strain gauges, four vibrating wire strain gauges and one accelerometer.
- Central Beam sections CENTRAL BEAM STA. 294+78.000 and CENTRAL BEAM STA. 305+22.000 will each be instrumented with one GPS unit.

3.8.1 CIBrE

- Provide and install all gauges listed above along with corresponding wires.
- Consult the contractor to determine appropriate blockout locations as not to interfere with constructability.
- Provide and install the 8″ x 8″ x 6″ foam blockout.
- Provide and install data loggers to record data during construction.

3.8.2 Contractor

- Provide access for four hours per section before the section is cast, but after the entire rebar cage is placed to the following Tie Beam/Central Beam sections: TB-T1U, TB-T1D, TB-T19U, TB-T19D, TB-T37U, and CENTRAL BEAM STA. 294+12.500 (University staff shall have access and means to reach the entire rebar cage) to install embedded gauges and blockouts.
- Provide 8 hours of access to the interior of the sections TB-T1U, TB-T1D, TB-T19U, TB-T19D, TB-T37U, and CENTRAL BEAM STA. 294+12.500 immediately after each has been cured to install accelerometers and data loggers.
- Provide four hours of access to the interior and top of the central beam at stations 294+78.000 and 305+22.000 immediately after each has been cured to install GPS units and data loggers.
- Upon request from the University approve or suggest the location of 8″ x 8″ x 6″ foam blockouts.
- Ensure that gauges, wires, and blockouts are not damaged once they are placed.

3.9 Roadway Section Responsibilities

This portion of the instrumentation program involves the installation of weldable foil strain gauges (embedded), vibrating wire strain gauges (embedded), and accelerometers (surface mounted) in selected roadway segments.

- Roadway sections to be instrumented include 1S-8, 1S-17, 2S-3U, 2S-3D, 2S-30U, 2S-30D, 2S-57U, 1N-8, 1N-17, 2N-3U, 2N-3D, 2N-30D, 2N-30U, and 2N-57U.
- Roadway sections 1S-8, 2S-3U, 2S-3D, 2S-30U, 2S-30D, 2S-57U, 1N-8, 2N-3U, 2N-3D, 2N-30D, 2N-30U, and 2N-57U will each be instrumented with four weldable foil strain gauges, four vibrating wire strain gauges and one accelerometer.
- Roadway sections 1S-17 and 1N-17 will each be instrumented with four vibrating wire strain gauges.

3.9.1 CIBrE

- Provide and install all gauges listed above along with appropriate wires.
- Consult the contractor to determine appropriate blockout locations as not to interfere with constructability.
- Provide and install the 8″ x 8″ x 6″ foam blockout .
- Provide and install data loggers to record data during construction.

3.9.2 Contractor

- Provide access for four hours per section to all roadway sections listed above before the section is cast but after the entire rebar cage is placed (University staff shall have access and means to reach the entire rebar cage) to install embedded gauges and blockouts (this will take place at the precasting plant).

- Provide 8 hours of access per section to the interior of all roadway sections listed above immediately after it has been placed for the installation of accelerometers and data loggers.
- Upon request from the University approve or suggest the location of 8″ x 8″ x 6″ foam blockouts.
- Ensure that gauges, wires, and blockouts are not damaged once they are placed.

3.10 Grouted Tendon Responsibilities

This portion of the instrumentation program involves the installation of void detection sensors in selected tendons of the bridge. The sensors will be able to detect voids in the grout and to identify whether the void is due to water or air. The purpose of the sensors will be to allow evaluation of the effectiveness of the grouting techniques used. The specific tendons to be instrumented have not been determined.

3.10.1 CIBrE

- Provide contractor with details of what tendons will be monitored.
- Provide and install all embedded gauges and wires (list types and quantities).

3.10.2 Contractor

- Provide appropriate extra hole in anchorages.
- Allow gauge wire to be pulled through tendon along with post-tensioning strand.
- Provide access to each section (2 hours of access per tendon) once after it has cured.

3.11 Through-Hole Responsibilities

This portion of the instrumentation program involves the installation of through-holes in selected segments of the bridge. Through-holes labeled as “UD Communication” in the bridge plans will be used to run gauge wires from roadway segments into adjacent tie/central beam where data acquisition equipment is located. For wires to be run from the roadway segments into the tie/central beam, there must be a hole in both the roadway segment and the tie/central beam. Furthermore, these holes must align to allow wires to be run through them. The holes also must remain clear once the closure pour between the roadway segment and tie/central beam is completed. It is anticipated that some sort of flexible or rigid conduit will be used to connect the holes in the roadway segments and central/tiebeam so that the closure pour does not fill in the wire way. A summary of the “UD Communication” through-hole locations is provided in Table 3.3.

There are also three through-holes in the bridge plans which are for monitoring equipment but are not labeled as “UD Communication.” These holes will be used for the installation of GPS units and wires. The location and purpose of these three holes are given in Table 3.4.

3.11.1 CIBrE

- Communicate with contractor to convey the intent of the holes and what criteria must be met for them to be functional.

3.11.2 Contractor

- Install “UD Communications” through-holes as per the bridge plans.
- Install through-holes for GPS units as per bridge plans.

- Ensure that “UD Communication” through-holes match within 1/8″, are of 2″ diameter, and are clear after the closure pour.

Table 3.3 “UD Communication” Through-Hole Segments

Tie-Beam Section/ Central Beam Station	Adjacent Roadway Sections		Reference Sheets
TB-T1D	NB SB	2N-3U 2S-3U	B-313 B-401 B-416
TB-T19D	NB SB	2N-30D 2S-30D	
TB-T37U	NB SB	2N-57U 2S-57U	
TB-T19U	NB SB	2N-30U 2S-30U	
TB-T1U	NB SB	2N-3D 2S-3D	
STA. 294+12.500	NB SB	1N-8 1S-8	B-334 B-401 B-416

Table 3.4 Other UD Through-Hole Segments

Central Beam Station/ Arch Section	Purpose	Reference Sheets
STA. 294+78.000	Southern Backspan	B-207
STA. 305+22.000	Northern Backspan	B-244
S-T36U	Arch Crown GPS	B-346

3.12 Data Collection During Construction

Data acquisition during construction will be accomplished by using temporary data loggers. The temporary data loggers will be installed once segments are cured (cast in place) or placed (precast) and will remain until hardwiring is run to the permanent data acquisition stations, which are shown in the electrical portion of the bridge plans.

It is anticipated that one data logger will be used at each instrumented section of the arch, tie beam, central beam, roadway segments, bearings, and at all GPS units and support cable load cells. A summary of all locations where temporary data loggers will be used in the bridge during construction is presented in Table 3.5. The data loggers that will be used are contained in small metal boxes (dimensions to be determined) that will run on internal batteries and record data from the gauges to which they are wired. The data loggers will need to be read (data will be physically retrieved from them by a UD staff member) once per week. Installation of the data loggers has been accomplished for each location in the corresponding chapter sections above. Therefore this section does not describe installation of the data loggers but instead focuses on responsibilities related to retrieving data from the data loggers.

Table 3.5 Location of temporary data loggers during construction*

* Does not include base station

Section/Location Type	Section Names	Channels Per Section
Strain Gauges in Arch Sections	S-C1U, S-C1D, S-T10U, S-T10D, S-T22U, S-T22D, S-T36U	4
GPS in Arch Section	S-T36U	1
Load Cells in Arch Sections	S-A9U, S-A9D, S-A21U, S-A21D, S-A33U	1
Strain Gauges in Tie Beam Sections	TB-T1U, TB-T1D, TB-T19U, TB-T19D, TB-T37U	4
Strain Gauges at Central Beam station	CENTRAL BEAM STA. 294+12.500	4
GPS at Central Beam Stations	CENTRAL BEAM STA. 294+78.000, 305+22.000	1
Southbound Roadway Sections	1S-8, 1S-17, 2S-3U, 2S-3D, 2S-30U, 2S-30D, 2S-57U	4
Northbound Roadway Sections	1N-8, 1N-17, 2N-3U, 2N-3D, 2N-30D, 2N-30U, 2N-57U,	4
Bearing Locations	Southern Arch Base, Southern Abutment, Northern Abutment	3,2,2

3.12.1 CIBrE

- Collect data on a weekly basis.

3.12.2 Contractor

- Provide access (one hour per data logger) to data loggers installed in the arch, central beam, tie-beam, roadway, and bearings in order to download data. It is anticipated that data will be retrieved from all installed data acquisition systems on a weekly basis until installation of the permanent data acquisition systems has been completed.

3.13 Installation of Permanent Data Acquisition Systems

Installation of permanent data acquisition equipment includes the running of gauge wires from gauges to permanent data acquisition locations, the running of communication cables from each data acquisition location to the UD communications enclosure at the southern end of the bridge, and the installation and set up of each data acquisition system. Permanent installation of data acquisition equipment can not take place until all "UD Communication" conduits have been installed, power has been connected to all "UD Receptacles," and the UD communications enclosure has been completed.

3.13.1 CIBrE

- Provide and install gauge wires from gauge locations to data acquisition system locations.
- Provide and install data acquisition systems.
- Provide and install communication cables from data acquisition systems to the UD communications enclosure located at the southern end of the bridge.

3.13.2 Contractor

- Install "UD Communications" conduits as per bridge plans.
- Install wire pulls in "UD Communications" conduit as per bridge plans.
- Install "UD Receptacles" as per bridge plans.
- Install UD communications enclosure as per bridge plans.
- Once the first four items in this section have been completed, provide a total of 56 hours of access to the interior of the entire

arch, southern backspan central beam, southern abutment, and the UD communications enclosure to allow hardwire connections to be run from gauges to data acquisition systems, and from data acquisition systems to the UD communications enclosure.

- Once the first four items in this section have been completed, provide a total of 56 hours of access to the interior of the entire tie beam, both central beams, all northbound roadway segments, all southbound roadway segments, the southern abutment, and the UD communications enclosure to allow hardwire connections to be run from gauges to data acquisition systems and from data acquisition systems to the UD communications enclosure.

CHAPTER 4

MONITORING PROJECT TIMELINE

4.1 Overview

The scope of the monitoring project necessitates a detailed organizational format for efficient management. This chapter outlines CIBrE's proposed organizational scheme and directs the reader to future chapters that specifically outline the stages involved in the project.

The monitoring project is scheduled to last from 09/01/04 to 08/31/10. In this six-year timeframe, the monitoring program will be developed, installed, activated, and continuously utilized.

Once a conceptual version of the monitoring project was developed, the University was in continual contact with Delaware Department of Transportation (owner), Figg Engineering Group (designer), and T.Y. Linn (independent design reviewer). This communication has allowed everyone involved in the project to fully understand the importance of the monitoring project and the overall effect it will have on all stages of design and construction. Additionally, in the near future, the University will be in constant contact with the chosen contractor to insure the correct installation, activation, and collection of monitoring data.

The project schedule is intended to allow CIBrE and its staff to efficiently manage the project, which comprises five distinct stages: Stage I – Preliminary Work, Stage II – Mechanically Stabilized Earth Wall Construction, Stage III – Bridge Construction, Stage IV – Initial Conditions, and Stage V – Long-Term Conditions.

After the five stages of the monitoring project were defined, a detailed flowchart was developed to help illustrate the sequence of events, as shown in Figure 4.1.

It can be seen from the figure that a large portion of the monitoring project takes place during the construction, requiring synchronization of the monitoring project schedule and the construction schedule. The schedule and timeline in this manual were developed from contacts with DelDOT and Figg and from the design drawing (provided by Figg). It is expected that some changes will be necessary once a construction schedule is generated by the contractor and construction begins. Every effort has been taken to minimize these changes through careful development of the monitoring project.

The following sections briefly outline the five main stages of the project. The main objective of each stage is laid out and a brief description of the major tasks that will be accomplished in each stage is given. As a result of the complexity of each of the stages described below, an individual chapter has been devoted to each stage that will discuss, in detail, the objectives and components of each.

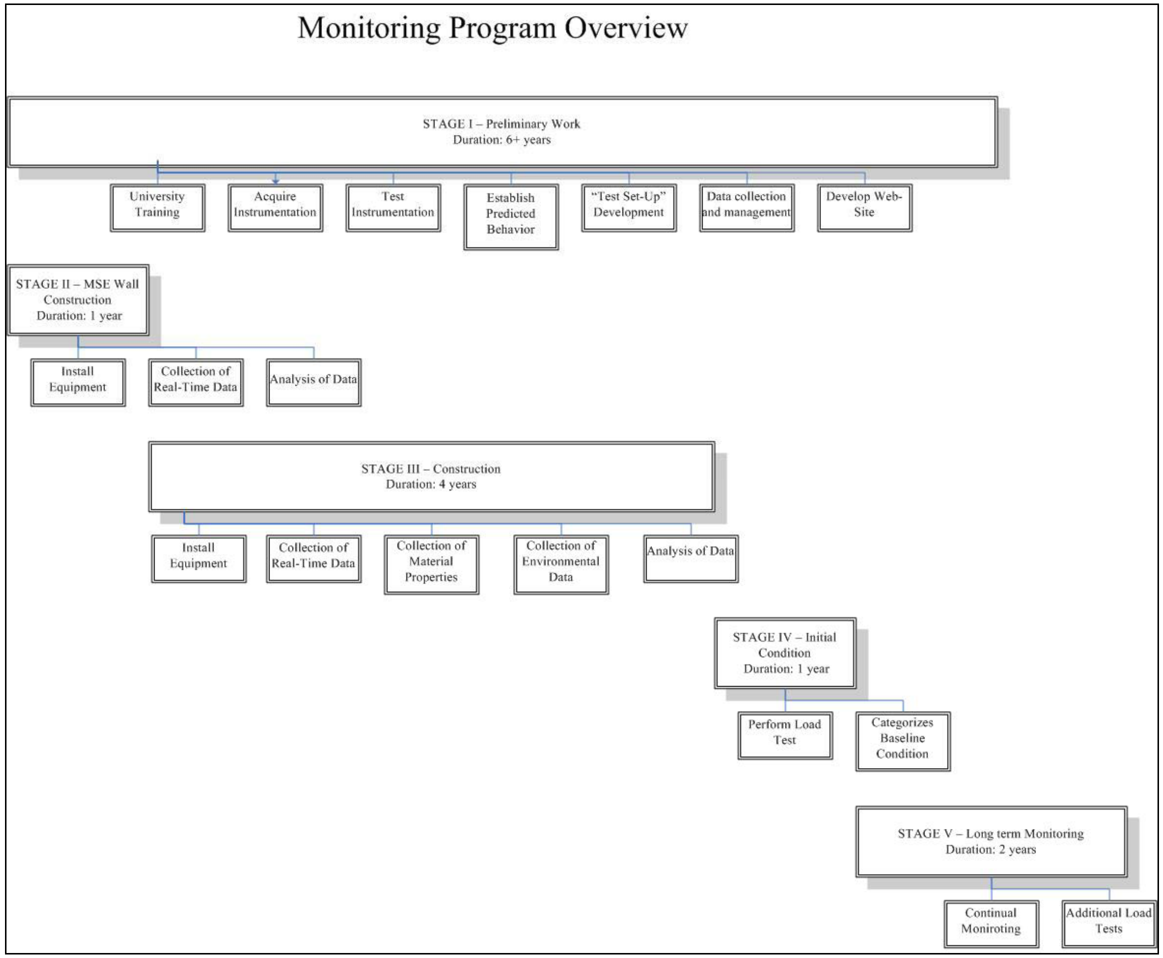

Figure 4.1 Monitoring Project Overview

4.1.1 Stage I - Preliminary Work

The primary objective of the preliminary work stage is to develop an efficiently organized management system that is capable of training University employees, acquiring and testing the instrumentation equipment, integrating and managing the collected data, and communicating the results via reports, web-sites, etc. to the desired persons.

The preliminary work on the monitoring project started when the project was proposed; work done during this stage laid the ground work for the remainder of the project. Stage I tasks include obtaining the required training (software and safety), acquiring all instrumentation equipment, establishing the predicted behavior of the bridge, developing a "test set-up" for the planned instrumentation, developing an efficient data collection and management system, and developing a website that is capable of displaying and archiving real-time monitoring data.

Stage specific objectives and components within Stage I will be discussed in greater detail in Chapter 5. Additionally, detailed schedules will be developed to assist in the completion of all aspects of Stage I.

4.1.2 Stage II – Mechanically Stabilized Earth Wall Construction

The primary objective of Stage II is to install all necessary strain gauges in the mechanically stabilized earth walls. Stage specific objectives and components within Stage II will be discussed in greater detail in Chapter 6. Additionally, detailed schedules will be developed to assist in the completion of all aspects of Stage II.

4.1.3 Stage III – Bridge Construction

The monitoring project will be implemented during construction. Implementation consists of installing and activating all instrumentation; commencing the collection of real-time monitoring data; creating a well-organized network and database of real-time monitoring data, material property data, and environmental conditions data; and verifying the predicted behavior of the bridge during construction.

Construction of the bridge is scheduled to take approximately four years. Major tasks during this stage include installation of all instrumentation equipment (gauges, data acquisition systems, global positioning system, gauge wires, and communication conduit), collection of real-time monitoring data, collection of material property data, documentation of environmental conditions, and analysis of real-time monitoring data.

Stage specific objectives and components within Stage III will be discussed in greater detail in Chapter 7. Additionally, detailed schedules will be developed to assist in the completion of all aspects of Stage III.

4.1.4 Stage IV - Initial Condition

At the completion of construction, important data must be gathered in order to classify the baseline behavior of the bridge. The primary task associated with this stage of the project is characterization of the response of the bridge to live load effects (thermal, wind, traffic) by performing various load tests on the bridge, collecting and correlating environmental data to real-time monitoring data, and characterizing the initial geometry of the bridge.

Stage IV will begin immediately following the completion of construction. It is expected that various tests will be conducted on the bridge before it is opened to traffic. Also, for certain baseline behaviors (ambient wind and traffic), monitoring will need to be conducted overtime. Consequently, Stage IV is predicted to last not more that one year.

Stage specific objectives and components within Stage IV will be discussed in greater detail in Chapter 8. Additionally, detailed schedules will be developed to assist in the completion of all aspects of Stage IV.

4.1.5 Stage V - Long-Term Condition

Once the baseline conditions of the bridge are determined through load testing and short-term monitoring, the long-term monitoring of the bridge will begin. The major objective of the long-term monitoring stage is to develop a long-term database of monitoring data and reports that will allow DelDOT to effectively monitor the structural health of the bridge throughout the service life of the bridge.

To accomplish this objective, the response of the bridge to live loads will be constantly monitored and compared to baseline measurements. The key areas of interest are the effectiveness of the bearings, the condition of selected post-tensioned cables, forces in the support cables, and internal strain in various sections of the bridge. Furthermore, every year the load tests (vehicle, ambient wind, etc.) will be conducted and compared to the initial load tests. It is anticipated that the University will conduct long-term monitoring on the bridge until the first scheduled bi-annual inspection.

Stage specific objectives and components within Stage V will be discussed in greater detail in Chapter 9. Additionally, detailed schedules will be developed to assist in the completion of all aspects of Stage V.

CHAPTER 5

STAGE I – PRELIMINARY WORK

5.1 Introduction

The primary objective of the preliminary work stage is to develop an efficiently organized management system. Given this objective, the primary tasks associated with this stage are obtaining the required training, acquiring all necessary monitoring equipment, developing a method to test and calibrate all monitoring equipment, developing an efficient data collection and management system, and developing a website that is capable of displaying and archiving real-time monitoring data. The following sections outline the necessary steps to accomplishing the objective of Stage I.

5.2 University Employee Training

University employees will need to be trained on how to install each gauge type, collect and read the data from each gauge type, and use the computer software necessary to operate the data acquisition systems. It is suggested that the manufacturers of the gauges and data acquisition systems provide some guidelines (owner's manuals) and possibly training courses that deal with project-specific conditions.

In addition, University employees will have to receive safety training. Most of the monitoring equipment will be installed in the field, which will require University employees to become certified in the required construction safety procedures as specified by the contractor. The University will independently certify all its employees at no cost to the contractor. The contractor and University will be in close contact once the project begins to ensure that the correct training is given in a timely manner. All training should be complete before any monitoring equipment is installed on the bridge. Decisions will need to be made as to who is going to be trained (graduate students, lab technicians, and/or professors) and what task each party will be responsible for during the length of the project.

5.3 Monitoring Equipment

During the preliminary work stage of the project all necessary monitoring equipment will need to be chosen and purchased. Plans have been laid out in Chapter 7, Stage III – Bridge Construction as to where the monitoring equipment is going to be installed. This should serve as a guide to help the University purchase the correct type and amount of monitoring equipment. In addition, a list of all vendor contact information should be generated. Once the final construction schedule is determined by the contractor the University will determine a final schedule for the acquisition and installation of all monitoring equipment. For additional specific information on the monitoring equipment please refer to Chapter 10 – Instrumentation.

5.4 Calibration and Equipment Testing

CIBrE will be responsible for testing and calibrating all the equipment acquired for the project. University employees will make sure that all gauges are working properly before they are installed in the field. Monitoring equipment should be tested and calibrated in accordance with the manufacturers' recommended methods.

Once the monitoring equipment is tested and calibrated, a plan should be developed for an "in-field" test to be conducted under conditions as close as possible to the actual monitoring set-up on the bridge. This test will help CIBrE determine whether the desired set-up is adequate for the task of gathering data.

5.5 Data Collection and Management System

The data collection and management system will consist of all necessary equipment to collect, store, and report the data, including data acquisition systems, gauge wire, communication cable, and central computers. The system should be able to operate without CIBrE interference for long periods of time. The main output of the system should be in graphical form and very easy for the user (i.e. DelDOT) to read and comprehend.

The data collection and management system should be tested in conjunction with the testing of the monitoring equipment. A complete system of gauges, wires, communication cable, data acquisition systems, central computers, and wireless communication should be set up and tested before any gauges are placed in the field.

A timeline should also be developed once the final construction schedule has been established by the contractor. This timeline should detail the required testing and the time at which testing should take place. This timeline will assist in the overall management of the project and is a must for the preliminary work stage of the project.

5.6 Real-Time Website

To effectively communicate the gathered data, a website that is capable of displaying the data will need to be created. The website designer should communicate with all involved parties (DelDOT, CIBrE, and the contractor) to determine what material will be included on the website and how the website is to look.

The website will consist of all the gathered data (i.e. strains, temperature, pressures, displacements, video, wind, etc.) in graphical form. The site will also include pictures of the bridge gauge locations. Webcams are also recommended as a feature of the site.

Users will be able to view archived data, load test data, construction documentation, and inspection reports. This data will aid in management of the bridge throughout its service life.

The primary website will be accessible to certain parties (DelDOT, CIBrE, and contractor). It should be password protected and a secure site. It is also believed that the data gathered can be used to educate the public about the Indian River Inlet Bridge. A public link could be added to the site showing basic real-time bridge behavior and other interesting information about the Indian River Inlet Bridge.

CHAPTER 6

STAGE II – MECHANICALLY STABILIZED EARTH WALL CONSTRUCTION

6.1 Overview

The mechanically stabilized earth walls being constructed as a part of the Indian River Inlet Bridge project will be very high, and settlement is expected to be significant. Therefore, the University of Delaware will install stain gauges on specific reinforcement panels to monitor the performance of the mechanically stabilized earth walls both during construction and over the intended service life. A detailed plan and schedule have yet to be developed for this phase of the project. Once a plan has been developed, the University will be in contact with DelDOT and the contractor to ensure the success of the roadway monitoring project.

For more information regarding the roadway monitoring program please see Appendix C – University of Delaware Roadway Monitoring Program Special Provisions.

CHAPTER 7

STAGE III – BRIDGE CONSTRUCTION

7.1 Introduction

During Stage III the instrumentation equipment will be installed and data collection initiated. This chapter first describes the monitoring instrumentation in detail. Plans are laid out for the locations of all instrumentation equipment and required hardwire connections. Additionally, a phased installation schedule, based primarily on the construction schedule, is developed and details are given regarding each instrumented location.

7.2 Instrumentation Program Description

To accomplish the objectives of the monitoring program, more than 240 permanent gauges, eleven data acquisition systems, 39 data loggers, and hundreds of feet of gauge wire and communication cable will be installed during the construction of the bridge. This instrumentation will allow CIBrE to effectively collect and store all the monitoring data necessary to quantify bridge behavior and allow DelDOT to efficiently manage the monumental structure.

Given the extent of the resources being devoted to the monitoring program, careful attention has been given to ensuring that the instrumentation installed will efficiently capture the behavior of the bridge during construction and its intended service life. The bridge behavior that will be captured by the monitoring program can be categorized into two types: event data and monitor data. Event data, defined as data that is gathered at high frequencies, is designed to document dynamic effects such as live load due to traffic and wind loading. Monitor data, defined as data that is gathered at low frequencies, is designed to document daily or seasonal effects such a thermal loads and settlement of the structure.

To collect all necessary event and monitor data, gauge locations and types have been selected to ensure that critical bridge behavior is quantified with a minimal number of gages. As a result, numerous types of gauges will be installed on and around the bridge, including vibrating wire gauges, weldable foil strain gauges, accelerometers, global positioning systems, load cells, linear potentiometers, chloride penetrations monitors, void detection devices, nitrogen monitoring gauges, a permanent weather station, and temporary anemometers. (For a detailed description of each gauge, its intended purpose, the manufacturer, the installation procedure, scheduling issues for each gauge and other information please refer to Chapter 10 – Instrumentation).

7.2.1 Permanent Instrumentation

Permanent instrumentation is defined as equipment (gauges and data acquisition systems) that will be installed during construction and will remain on the bridge for the duration of the monitoring program. A total of 25 locations on the bridge will be instrumented. The chosen instrumented sections include south abutment, north abutment, south arch base, south pile cap, arch-rib, tie-beam, central beam, support load cables (installed internally to the arch-rib), southbound roadway sections, northbound roadway sections, and post-tensioning tendon ducts. All locations will be instrumented with gauges that will be used to collect data on bridge response. Additionally, several locations will be instrumented with data acquisition systems for the purpose of collecting, storing and communicating the gathered real-time data.

7.2.1.1 Permanent Gauge Location

As stated before, permanent gauges will be installed at 25 locations on the bridge. Figures 7.1 and 7.2 detail the locations of permanent gauges. Furthermore, Table 7.1 defines the planned permanent gauge locations by describing the locations that will be instrumented and the gauge types that will be installed at each location. Table 7.5, located at the end of Section 7.2, describes the abbreviations used in the tables located in Section 7.2.[1]

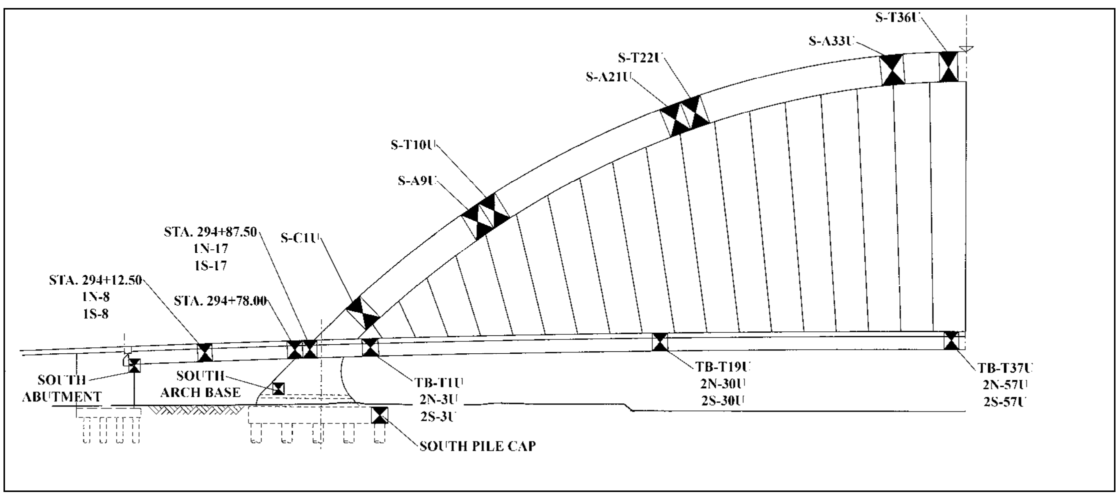

Figure 7.1 South Permanent Gauge Locations (Modified IRIB Specifications and Construction Plans)

[1] The labeling scheme that was used to identify instrumented segments (i.e. arch segment S-A9U) was developed from the IRIB Specifications and Construction Plans. All Figures and Tables throughout the manual use this labeling scheme. Appendix D provides a complete list of design drawings used in the development of the monitoring program. The reference design drawings will provide the complete labeling scheme for all bridge segments.

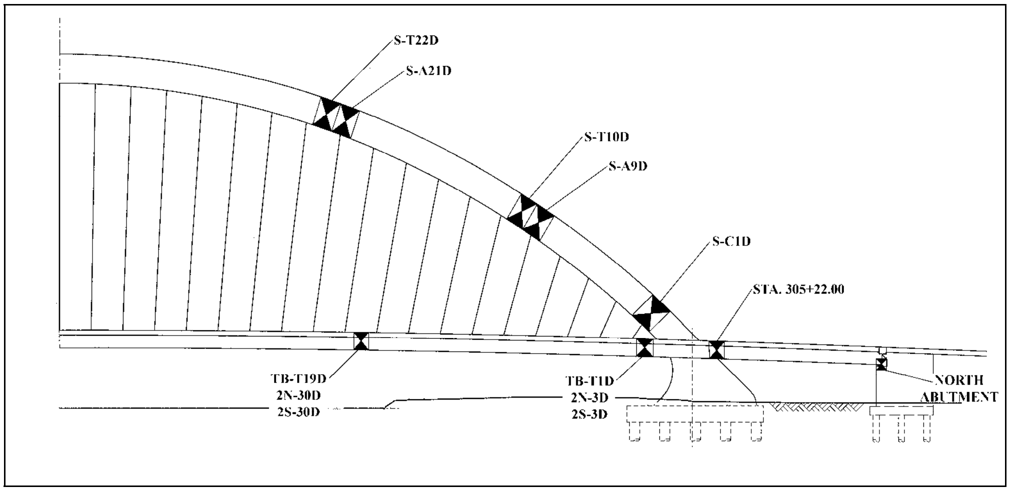

Figure 7.2 North Permanent Gauge Locations (Modified IRIB Specifications and Construction Plans)

Table 7.1 Permanent Gauge Locations and Associated Gauges

<table>
<tr><th><u>Location</u></th><th><u>Instrumentation</u></th></tr>
<tr><td></td><td></td></tr>
<tr><td>Pile Cap</td><td></td></tr>
<tr><td>South Pile Cap</td><td>4 CM</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Abutment</td><td></td></tr>
<tr><td>North Abutment</td><td>2 LP</td></tr>
<tr><td>South Abutment</td><td>2 LP</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Arch Base</td><td></td></tr>
<tr><td>South Arch Base</td><td>3 LP</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Prestressing Tendon Ducts</td><td></td></tr>
<tr><td>Location to be Determined</td><td>VD</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Arch-Rib Section</td><td></td></tr>
<tr><td>S-C1U</td><td rowspan="6">4 VW, 4 FS, 1 ACC</td></tr>
<tr><td>S-T10U</td></tr>
<tr><td>S-T22U</td></tr>
<tr><td>S-T22D</td></tr>
<tr><td>S-T10D</td></tr>
<tr><td>S-C1D</td></tr>
<tr><td>S-T36U</td><td>4 VW, 4 FS, 1 ACC, 1 GPS</td></tr>
<tr><td>S-A9U</td><td rowspan="5">1 LC, NM</td></tr>
<tr><td>S-A21U</td></tr>
<tr><td>S-A33U</td></tr>
<tr><td>S-A21D</td></tr>
<tr><td>S-A9D</td></tr>
</table>

<table>
<tr><th>Tie-Beam Section/Central Beam Station</th><th colspan="2">Adjacent Roadway Sections</th><th>Instrumentation in Tie-Beam/Central Beam</th><th>Instrumentation in Roadway</th></tr>
<tr><td rowspan="2">TB-T1U</td><td>NB</td><td>2N-3U</td><td rowspan="12">4 VW, 4 FS, 1 ACC</td><td rowspan="12">4 VW, 4 FS, 1 ACC</td></tr>
<tr><td>SD</td><td>2S-3U</td></tr>
<tr><td rowspan="2">TB-T19U</td><td>NB</td><td>2N-30U</td></tr>
<tr><td>SB</td><td>2S-30U</td></tr>
<tr><td rowspan="2">TB-T37U</td><td>NB</td><td>2N-57U</td></tr>
<tr><td>SB</td><td>2S-57U</td></tr>
<tr><td rowspan="2">TB-T19D</td><td>NB</td><td>2N-30D</td></tr>
<tr><td>SB</td><td>2S-30D</td></tr>
<tr><td rowspan="2">TB-T1D</td><td>NB</td><td>2N-3D</td></tr>
<tr><td>SB</td><td>2S-3D</td></tr>
<tr><td rowspan="2">294+12.500</td><td>NB</td><td>1N-8</td></tr>
<tr><td>SB</td><td>1S-8</td></tr>
<tr><td rowspan="2">294+87.500</td><td>NB</td><td>1N-17</td><td rowspan="2">N/A</td><td rowspan="2">4 VW</td></tr>
<tr><td>SB</td><td>1S-17</td></tr>
<tr><td rowspan="2">294+78.000</td><td>NB</td><td>N/A</td><td rowspan="4">1 GPS</td><td rowspan="4">N/A</td></tr>
<tr><td>SB</td><td>N/A</td></tr>
<tr><td rowspan="2">305+22.000</td><td>NB</td><td>N/A</td></tr>
<tr><td>SB</td><td>N/A</td></tr>
</table>

7.2.1.2 Data Acquisition System Locations

For the purpose of collecting, storing, and communicating real-time data, eleven data acquisition systems will be installed. Figures 7.3 and 7.4 detail the location of data acquisition systems, and Table 7.2 details the gauge distribution to all data acquisition systems.

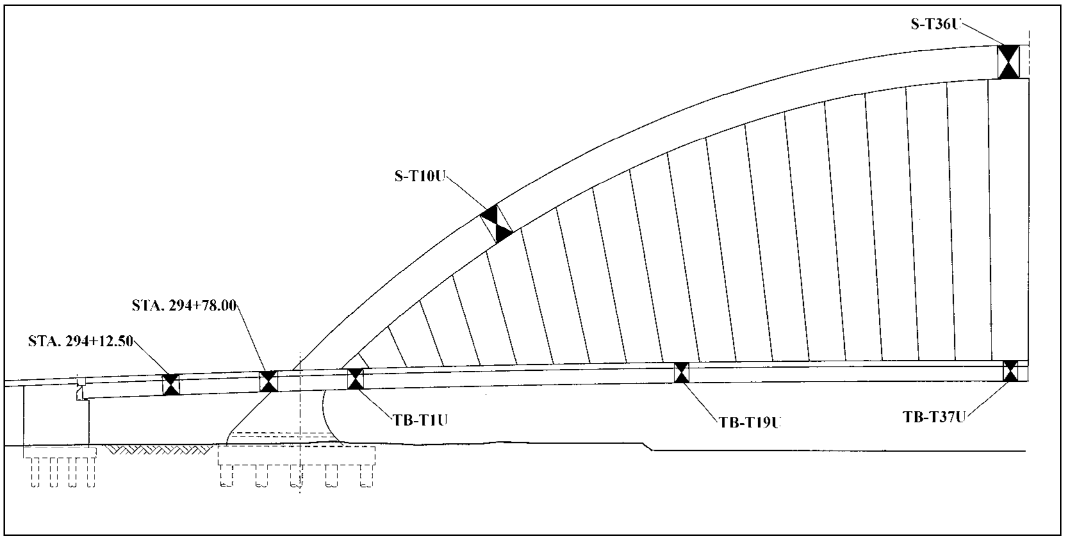

Figure 7.3 South Data Acquisition System Locations (Modified IRIB Specifications and Construction Plans)

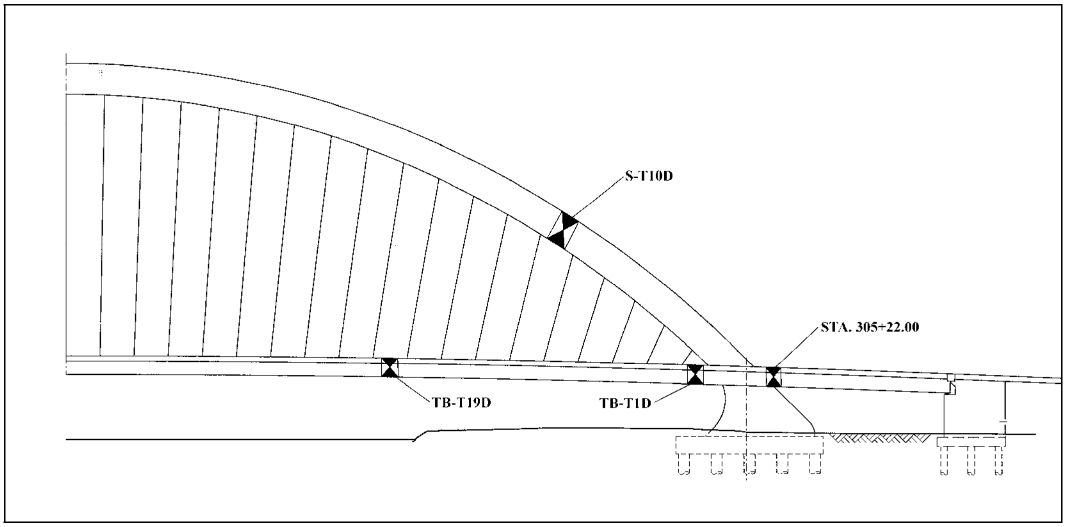

Figure 7.4 North Data Acquisition System Locations (Modified IRIB Specifications and Construction Plans)

Table 7.2 Gauge Distribution to Data Acquisition Systems

Data Acquisition Unit Location	Vibrating Wire	Weldable Foil	Accelerometer	GPS	Load Cell	Linear Potentiometer	Total
S-T10U	12	12	3	0	2	0	29
S-T36U	4	4	1	1	1	0	11
S-T10D	12	12	3	0	2	0	29
TB-T1U	20	12	3	0	0	3*	36
TB-T19U	12	12	3	0	0	0	26
TB-T37U	12	12	3	0	0	0	26
TB-T19D	12	12	3	0	0	0	26
TB-T1D	12	12	3	0	0	0	26
Central Beam 294+12.500	12	12	3	0	0	0	26
Central Beam 294+78.000	0	0	0	1	0	0	1
Central Beam 305+22.000	0	0	0	1	0	0	1
Total Number of Gages	108	100	19	3	5	2	237
* Final sensor routing to be determined by the contractor							

7.2.2 Temporary Instrumentation

Temporary instrumentation is defined as equipment (gauges and data loggers) that will be installed during the construction of the bridge but will not remain on the bridge during its intended service life. All permanent instrumented locations will be temporarily instrumented with data logger systems in order to collect real-time monitoring data during construction. Also, the south temporary construction tower and its temporary stays will be instrumented with temporary gauges to quantify wind behavior at the site and forces in the temporary stays

7.2.2.1 Temporary Gauge Locations

As stated before, temporary gauges (anemometers and load cells) will be installed on the south temporary construction tower and on the temporary stays. Currently the design of the temporary towers has not been completed. As a result, the CIBrE team has not been able to finalize its intentions with respect to the temporary gauges (anemometers and load cell) and their respective locations. Once the final tower design is complete and the intended construction sequence is finalized, CIBrE will be able to define the exact number and location of the temporary gauges and provide details about how the gauges will be installed. Please see Sections 3.4.1 and 3.4.2 for more details regarding the responsibilities CIBrE and the contractor with regard to the temporary construction towers.

7.2.2.2 Data Logger System Locations

To capture real-time monitoring data at the beginning stages of construction, data logger systems will need to be installed at every permanent instrumentation location (see Figures 7.5 and 7.6). In Figure 7.7 the location of the base station is described. The base station will be installed to collect real-time monitoring data from the gauges located on the temporary tower and temporary stays. Table 7.3 details the gauge distribution to all temporary data logger systems. It is intended that the temporary data acquisition systems will run off battery power for the length of time that they are needed.

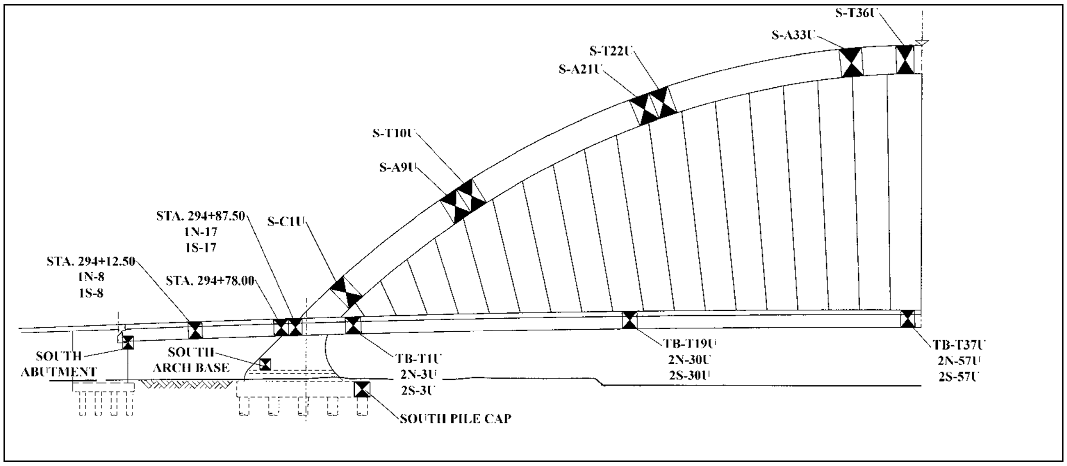

Figure 7.5 South Data Logger System Locations (Modified IRIB Specifications and Construction Plans)

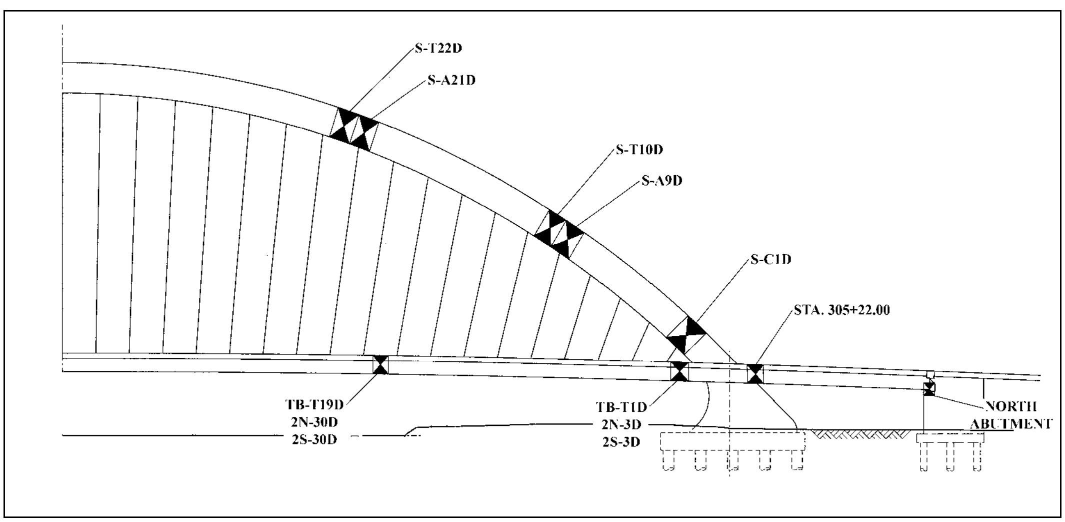

Figure 7.6 North Data Logger Locations (Modified IRIB Specifications and Construction Plans)

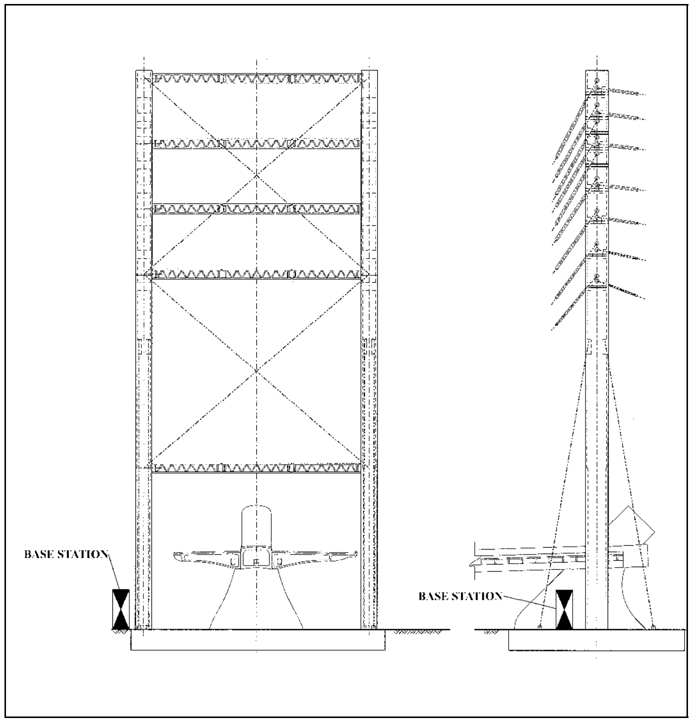

Figure 7.7 Base Station Location (Modified IRIB Specifications and Construction Plans)

Table 7.3 Gauge Distribution for Data Logger Systems

Data Logger Unit Location	Gauge Type	
Arch Base	**Linear Potentiometer**	
South Arch Base	3	
Abutment	**Linear Potentiometer**	
South Abutment	2	
North Abutment	2	
Arch-Rib Section	**Vibrating Wire**	**Load Cell**
S-C1U	4	0
S-A9U	0	1
S-T10U	4	0
S-A21U	0	1
S-T22U	4	0
S-A33U	0	1
S-T36U	4	0
S-T22D	4	0
S-A21D	0	1
S-T10D	4	0
S-A9D	0	1
S-C1D	4	0
Central Beam Station		
294+12.50	4	
Tie-Beam Sections		
TB-T1U	4	
TB-T19U	4	
TB-T37U	4	
TB-T19D	4	
TB-T1D	4	

Data Logger Unit Location	Gauge Type	
Roadway Sections	**Vibrating Wire**	
1N-8	4	
1S-8	4	
1N-17	4	
1S-17	4	
2N-3U	4	
2S-3U	4	
2N-30U	4	
2S-30U	4	
2N-57U	4	
2S-57U	4	
2N-30D	4	
2S-30D	4	
2N-3D	4	
2S-3D	4	
Temporary Tower	**Anemometer**	**Load Cell**
Base Station	XXX	XXX
Global Positioning System Locations		
S-T36U		
294+78.00		
305+22.00		

Total Temporary System Requirements		
Number of Locations	39	
Number of Gauges	#VALUE!	

7.2.3 Hardwire Connections

To communicate the gathered data to a central computing station (UD communication enclosure located just west of the south abutment), hardwire connections must be made between instrumented locations. There are two types of connections that will need to be made, gauge wire connections and communication cable connections. The following sections define and describe the required hardwire connections.

7.2.3.1 Gauge Wire Connections

Gauge wire connections are defined as connections necessary between locations of instrumentation without a data acquisition system (e.g., Arch-Rib Section S-C1U) and locations of instrumentation with a data acquisition system (e.g., Arch-Rib Section S-T10U) so that real-time monitoring data can be collected and stored. Figure 7.8 details the required gauge wire routing.

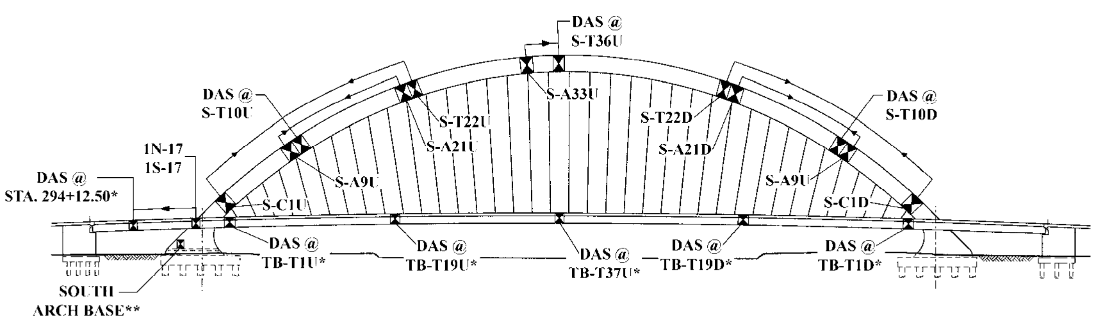

Figure 7.8 Gauge Wire Routing Schematic (elevation view) (Modified IRIB Specifications and Construction Plans)

Three types of gauge wire routing will be necessary. The first type is routing from one location to another via "long" wire runs. This is indicated by the black solid lines in Figure 7.8. There are nine such wire runs in the arch-rib section and one in the south back span. These "long" wire runs will be installed in the local conduit provided by the contractor and specified in the bridge plans. Secondly, gauge wire runs will need to be made from adjacent roadway sections to tie-beam locations. In Figure 7.8 an asterisk (*) denotes this type of connection. These connections will be made via through-holes located in both the adjacent roadway and tie-beam sections. Figure 7.9 depicts the through holes and required routing of the gauge wires.

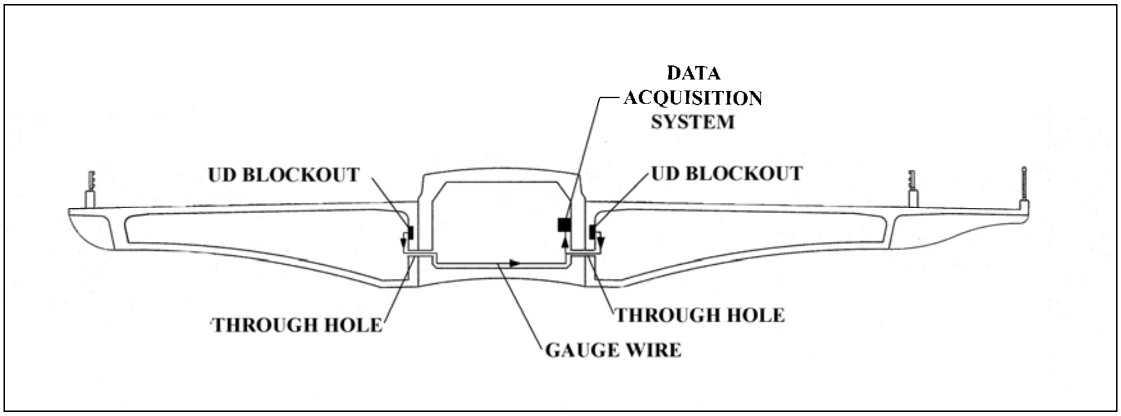

Figure 7.9 Typical Roadway Section to Tie-Beam Gauge Wire Connection (Modified IRIB Specifications and Construction Plans)

Finally, gauge wire will need to be run from the south arch base to a data acquisition location. In Figure 7.8 these locations are denoted with a double asterisk (**). It is up to the contractor to decide how these gauge wires will be routed. The contractor has two options. The first option is to route the wires up through the arch base and into the tie-beam sections (as specified in the bridge plans). The second option is to route the wire underground directly to the UD communication enclose located nearby. CIBrE will work closely with the contractor to determine the best course of action.

Table 7.4 further describes the gauge wire connections by giving a detailed description of the routing schematic, the required distances, and the number of gauges that will be needed to be routed.

Table 7.4 Sensor Wire Routing Connection Details

Data Acqusition System Location	Connecting Segment	Number of Gauges in Connecting Segment*	Distance Between Segments (Center to Center) (ft)
S-T10U	S-C1U	9	131.4
	S-A9U	1	14.6
	S-A21U	1	160.6
	S-T22U	9	175.2
S-T36U	S-A33U	1	43.8
S-10D	S-C1D	9	131.4
	S-A9D	1	14.6
	S-A21D	1	160.6
	S-T22D	9	175.2
TB-T1U	2N-3U	9	Through Hole Access
	2S-3U	9	Through Hole Access
TB-T19U	2N-30U	9	Through Hole Access
	2S-30U	9	Through Hole Access
TB-T37U	2N-57U	9	Through Hole Access
	2S-57U	9	Through Hole Access
TB-T19D	2N-30D	9	Through Hole Access
	2S-30D	9	Through Hole Access
TB-T1D	2N-3D	9	Through Hole Access
	2S-3D	9	Through Hole Access
STA. 294+12.50	1N-8	9	Through Hole Access
	1S-8	9	Through Hole Access
	1N-17	9	75.0
	1S-17	9	75.0

* Number of gauges does not include gauges located in the section with the data acquisition system

7.2.3.2 Communication Cable Connections

Communication cable connections are defined as connections necessary to transfer collected data from a data acquisition system to the UD communication enclosure located near the south abutment of the bridge. Communication cable will be installed after construction is complete. The cable will be installed in the communication conduit provided by the contactor and detailed in the bridge plans. Figure 7.10 details the communication routing.

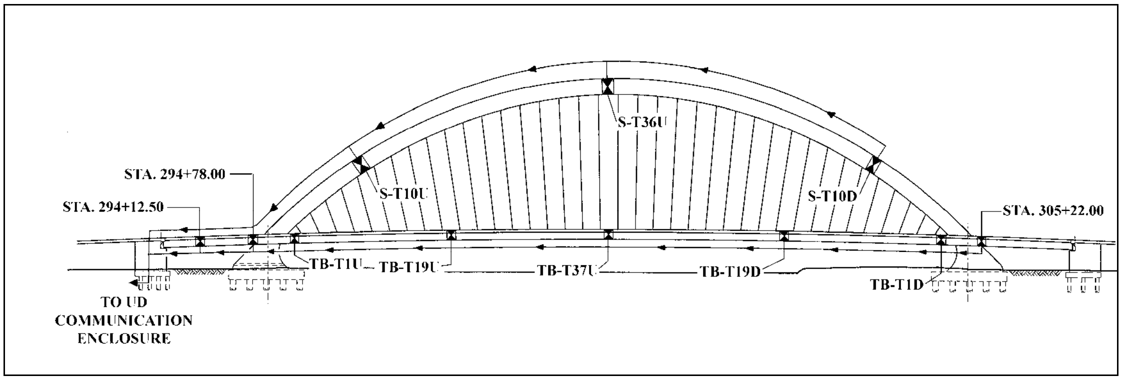

Figure 7.10 Communication Cable Routing Schematic (elevation view) (Modified IRIB Specifications and Construction Plans)

Table 7.5 Legend Abbreviations

Sensor	Abbreviation
Vibrating Wire Gages	VW
Weldable Foil Strain Gages	FS
Accelerometers	ACC
Global Position System	GPS
Load Cells	LC
Nitrogen Monitoring System	NM
Anemometers	A
Linear Potentiometers	LP
Corrosion Monitoring	CM
Void Decection Device	VD

7.3 Phased Implementation of Monitoring Equipment

The task of implementing the monitoring program consists of all activities relating to the installation, activation, and initial data collection of the instrumentation equipment. Additionally, during construction of the bridge CIBrE will monitor the environmental conditions at the site and will work closely with the DelDOT Materials Division to create a database of material properties. The data collected by the monitoring equipment will enable CIBrE to track both construction loads and the evolution of dead load stresses throughout the structure.

It is intended that as the bridge is being constructed all permanent instrumentation equipment will be installed as soon as possible. This means that both the construction schedule and the installation of the instrumentation equipment schedule will be very similar. As a result, there is a need for continual contact with the chosen contractor to ensure that the instrumentation equipment gets installed in the proper locations and at the correct time.

7.3.1 General Construction Sequence

A schedule for the installation of the monitoring equipment has been developed based on the proposed construction schedule detailed in the final bridge plans (Figg Engineering Group). With regard to the monitoring program, the proposed construction schedule can be broken down into two parts: preliminary work and the general construction sequence. During preliminary work the deep foundation will be constructed and the south arch base pile cap will be instrumented. During the general construction sequence, the majority of the instrumentation will be installed. For the purpose of easily identifying when each gauge will be installed, the general construction sequence has been broken down into six distinct steps, as shown in Figures 7.11 through 7.16. During Step 1 (Figure 7.11) of construction, arch bases, temporary towers, the cast-in-place central beam, and both northbound and southbound roadway segments are erected. In Step 2 (Figure 7.12), the arch-rib is constructed and temporary support cables are installed to support the arch. Next, in Step 3 (Figure 7.13) a closure segment is cast in the arch-rib and the arch-rib is complete. During Step 4 (Figure 7.14) the tie-beam segments are constructed, along with associated support cables. Step 5 (Figure 7.15) depicts the closure segment casting of the tie-beam. Finally in Step 6 (Figure 7.16) all northbound and southbound roadway segments are erected, temporary supports are removed and the bridge is complete. A more detailed construction schedule will be provided by the contractor, and a review of this schedule is necessary to ensure that proper installation of all monitoring equipment can take place.

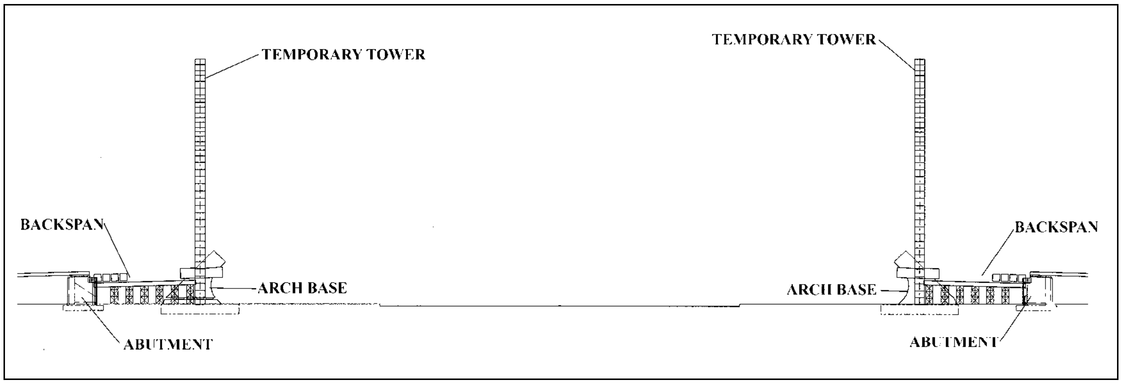

Figure 7.11 Step 1-Construct Approach Spans (Modified IRIB Specifications and Construction Plans)

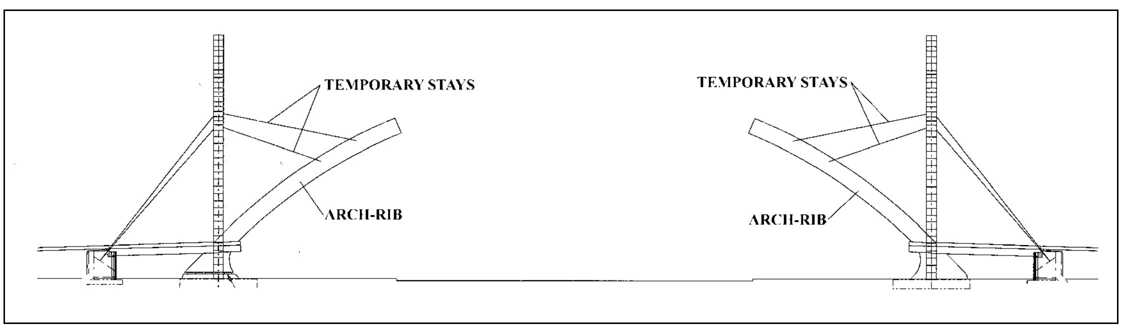

Figure 7.12 Step 2-Construct Arch (Modified IRIB Specifications and Construction Plans)

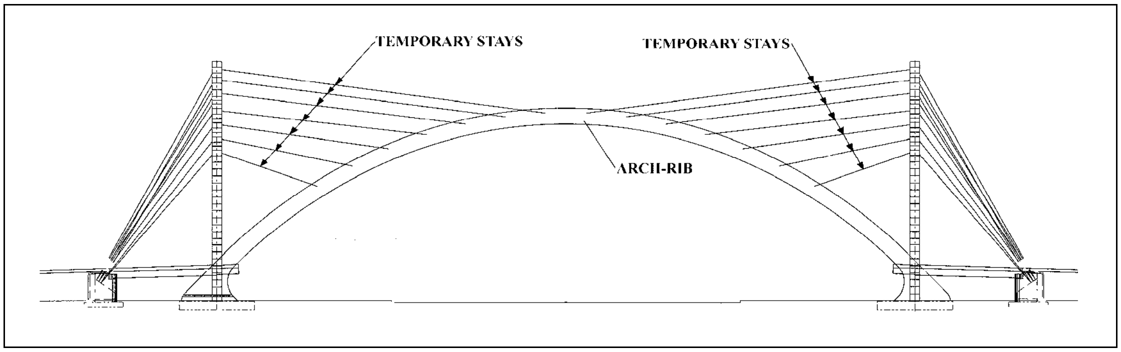

Figure 7.13 Step 3-Complete Arch (Modified IRIB Specifications and Construction Plans)

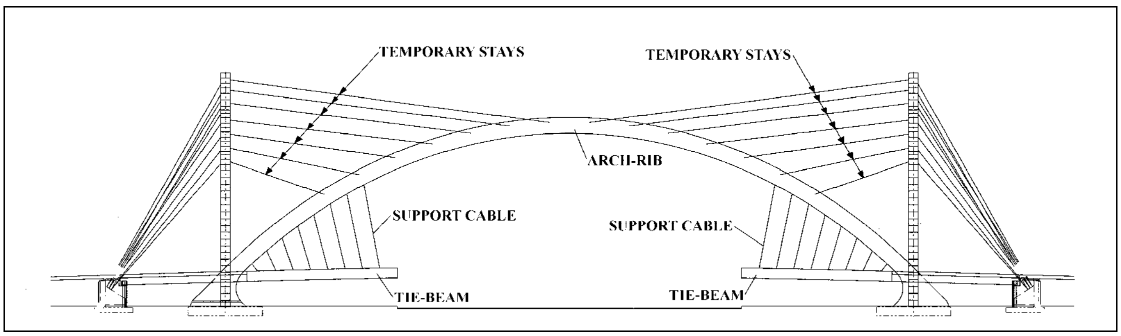

Figure 7.14 Step 4-Construct Tie-Beam (Modified IRIB Specifications and Construction Plans)

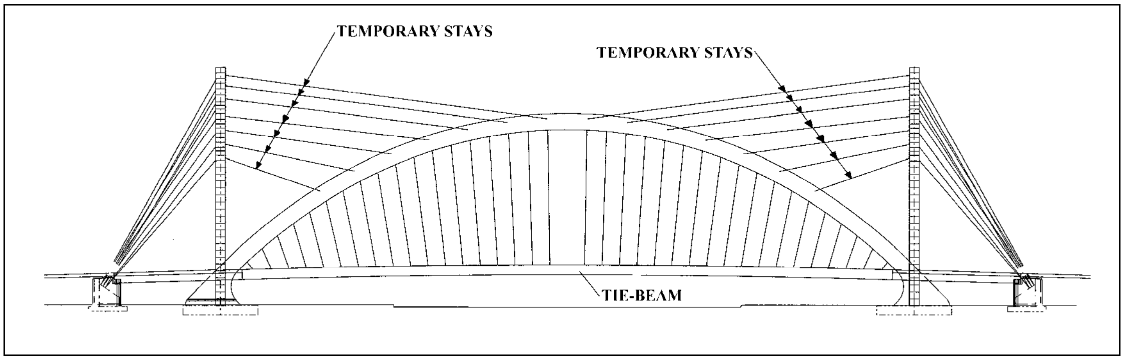

Figure 7.15 Step 5-Complete the Tie-Beam (Modified IRIB Specifications and Construction Plans)

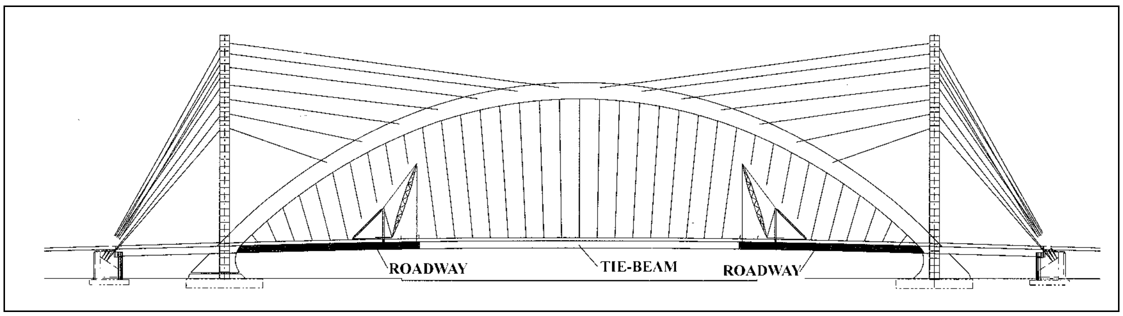

Figure 7.16 Step-6 Erect Main Span Deck (Modified IRIB Specifications and Construction Plans)

7.3.2 General Instrumentation Schedule

Once the proposed construction sequence was determined, a detailed schedule was laid out for the installation of all instrumentation equipment. Based on the construction schedule the monitoring equipment installation can be broken down into seven different phases. Each phase corresponds to a portion of the bridge that will be instrumented with equipment. Table 7.6 describes the specific section of the bridge that will be instrumented in each phase.

Table 7.6 Instrumented Locations

Instrumentation Phase	Instrumented Location
Phase 1	South Arch Base Pile Cap
Phase 2	South Arch Base
Phase 3	South Temporary Tower
	Temporary Stays
Phase 4	Abutment Bearings
	Central Beam
	Roadway
Phase 5	Arch-Rib
Phase 6	Tie-Beam
Phase 7	Roadway

Due to the uncertainty of the construction sequence, it has been possible only to generate idealized flowcharts of the events that will take place during implementation of the monitoring equipment. Figure 7.17 generally describes when and what types of instrumentation will be installed. No overall timelines have been set for the project.

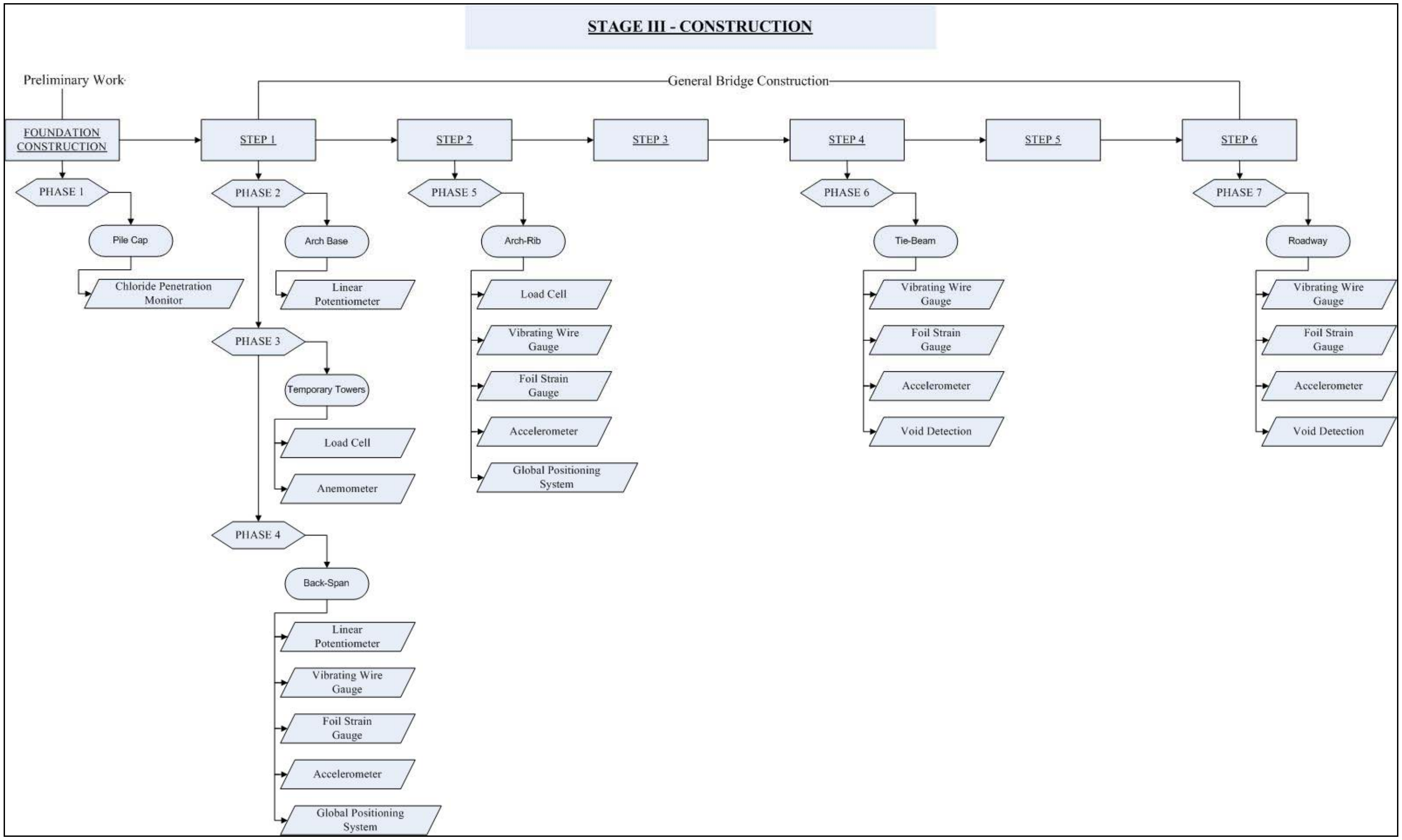

Figure 7.17 Monitoring Equipment Installation Schedule

The following sections outline the proposed monitoring instrumentation in more detail.

7.4 Phase 1 - Pile Cap Instrumentation

Before Step 1 of the general construction sequence (Section 7.3.1), the foundation for the bridge will be constructed. CIBrE plans to instrument the south pile cap with chloride penetration monitors. The following section outlines CIBrE intentions for the instrumentation of the south pile cap.

7.4.1 South Pile Cap

To monitor corrosion of the pile cap, chloride penetration monitors will be installed in the South Arch Pile Cap. It is intended that four units will be installed in the foundation cap, one at each corner of the pile cap. Currently there are two options for the foundation, drilled shafts and driven steel pipe piles. It is up to the contractor to decide which option to use. Figures 7.18 and 7.19 detail the proposed location of the chloride penetration monitors. Exact locations of the monitoring equipment will need to be discussed with the contractor and a final location will need to be decided upon. Also, exact locations of the “block-out” will need to be determined.

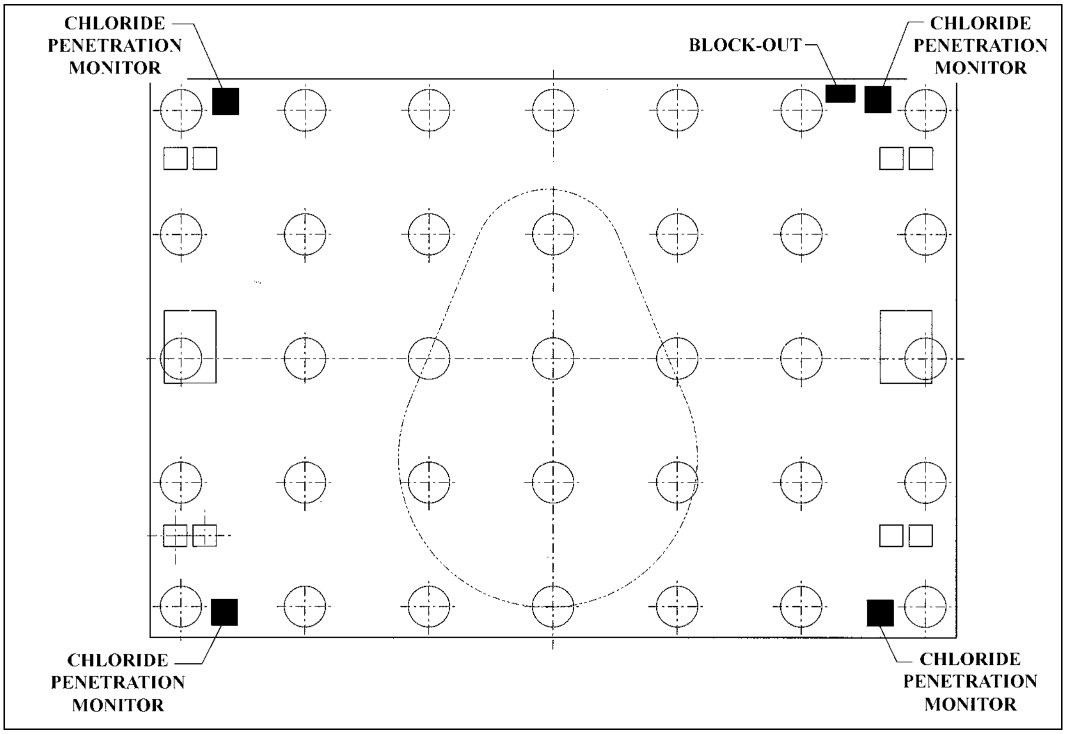

Figure 7.18 Chloride Penetration Monitor Locations (Plan View) (Modified IRIB Specifications and Construction Plans)

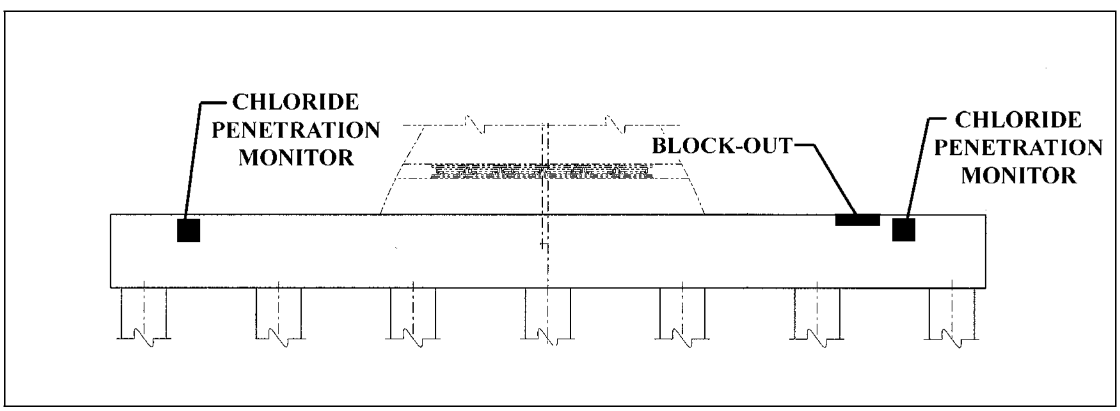

Figure 7.19 Chloride Penetration Monitor Locations (Elevation View) (Modified IRIB Specifications and Construction Plans)

The design of the chloride penetration monitoring equipment has not yet been finalized. It is unclear where the gauge wires will be routed to tie into the monitoring system and how often data will need to be gathered. When more details are obtained about the chloride penetration monitors and the pile cap, CIBrE will provide the contractor and DelDOT with the required information to ensure the proper installation of the gauges and collection of data.

Further installation details and procedure for the chloride penetration monitors can be found in Chapter 10 – Instrumentation.

7.5 Phase 2 - Arch Base Instrumentation

During Step 1 of the general construction sequence (Section 7.3.1), the arch bases will be erected. CIBrE plans to instrument the south arch base with linear potentiometers. The following section outlines CIBrE intentions for the instrumentation of the south arch base.

7.5.1 South Arch Base

To of quantify linear displacement of the bridge due to live load effects, linear potentiometers will be installed in the South Arch Base. It is intended that three bearings will be instrumented with linear potentiometers. Figures 7.20 and 7.21 detail the locations of the three linear potentiometers. Exact locations of the monitoring equipment will need to be discussed with the contractor.

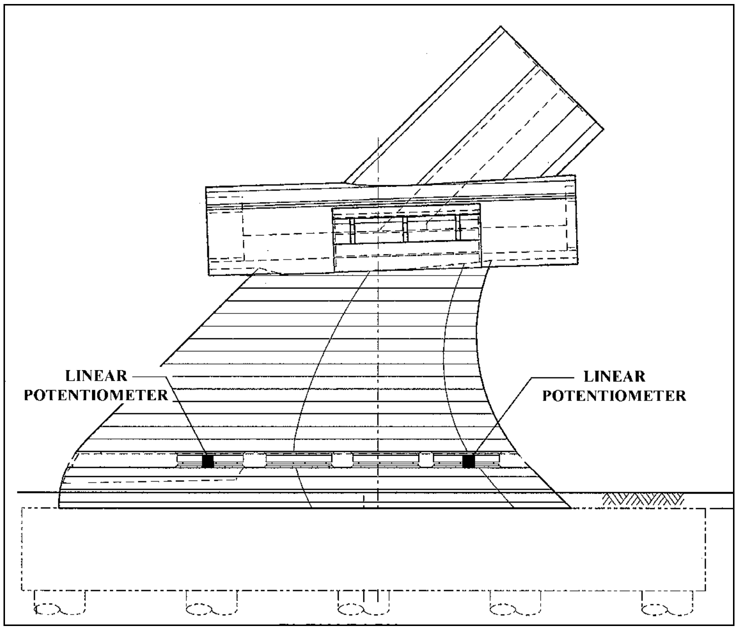

Figure 7.20 Linear Potentiometer Locations (Elevation View) (Modified IRIB Specifications and Construction Plans)

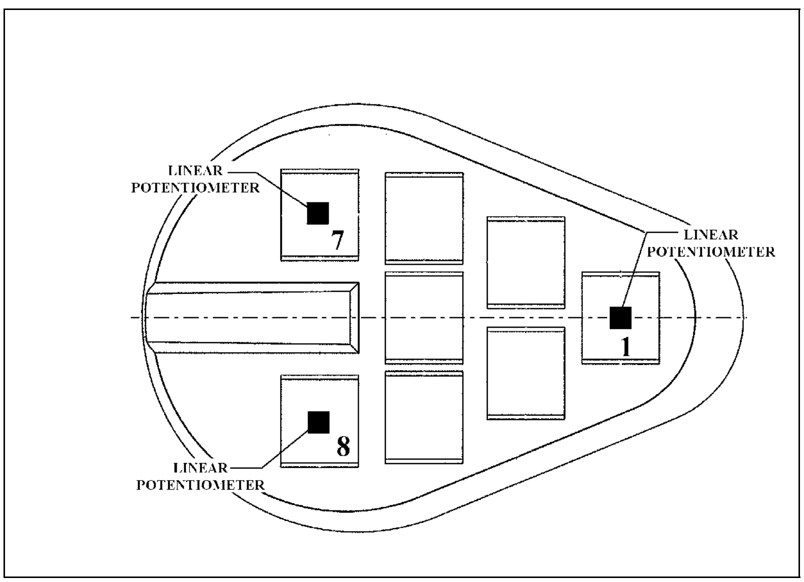

Figure 7.21 Linear Potentiometer Locations (Plan View) (Modified IRIB Specifications and Construction Plans)

The linear potentiometers will be installed as the south arch base is being constructed. It is anticipated that as soon as the bearings are installed, the linear potentiometers will be placed. The linear potentiometers will be installed in such a manner as to allow for data to be gathered as the arch base is being finished, during verification of the bearings; ability to displace, during the bearing blocking procedures, and after the bearings are unblocked at the end of construction.

Data collection for the linear potentiometers will be in two phases. The first phase will be temporary data collection using a data logger system. This system will be installed at the same time the bearing instrumentation is installed and is intended for use throughout construction. Phase two of data collection is permanent data collection using one of two methods. The contractor will determine hoe to hardwire the linear potentiometers into the monitoring system and notify the University as soon as possible after making a decision. One option is to use conduit installed in the arch base (see bridge plans) to route gauge wire to a data acquisition system located in the tie-beam. The second option is to provide access for the gauge wires to be routed directly to UD communication enclosure. Figure 7.22 details the installation scheduled for the three linear potentiometers and describes the intended data acquisition system requirements and sequencing.

Further installation details and procedure for the linear potentiometers can be found in Chapter 10 - Instrumentation.

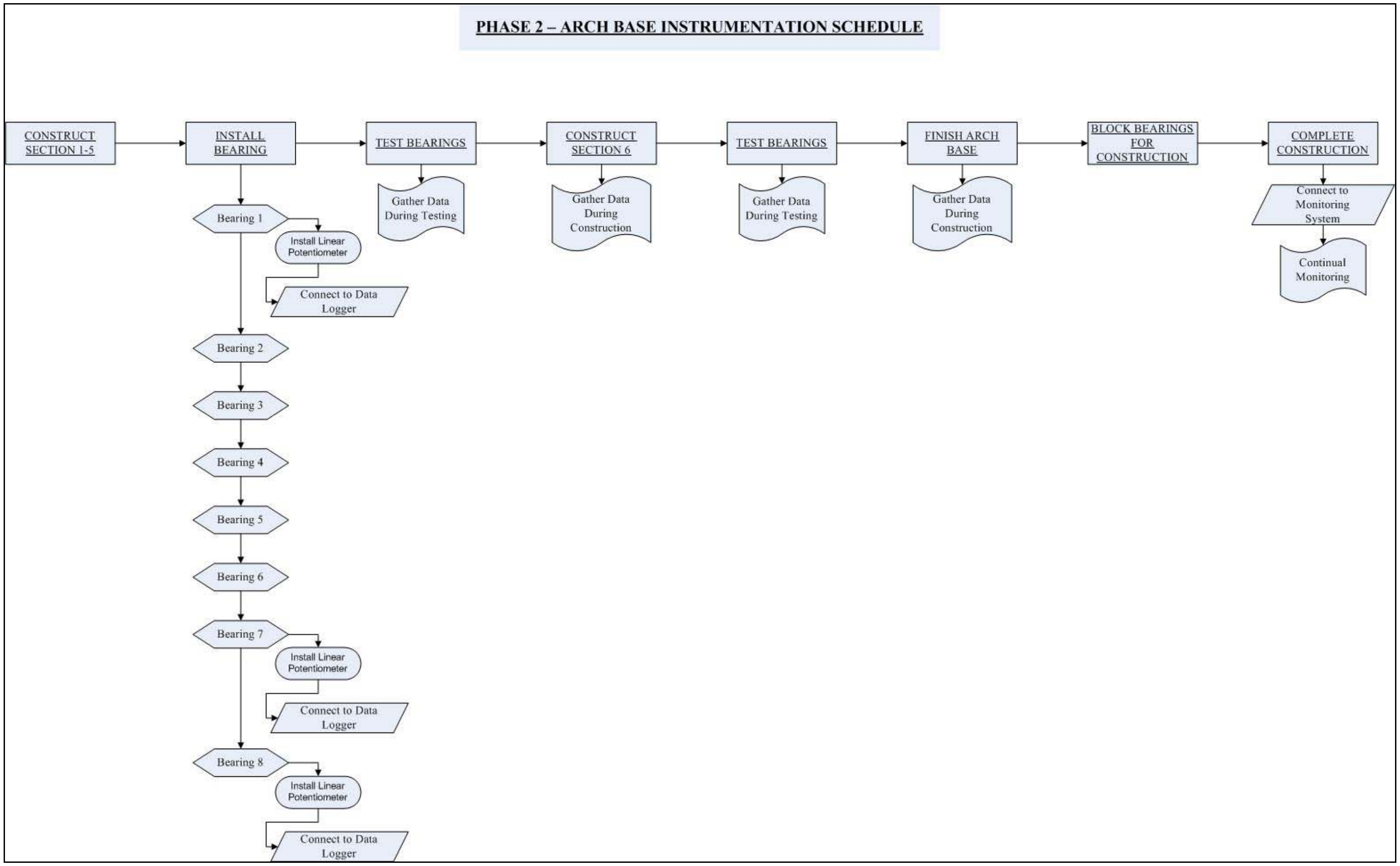

Figure 7.22 Linear Potentiometer Installation Schedule

7.6 Phase 3 - Temporary Tower Instrumentation

As a part of Step 1 of the general construction sequence (Section 7.3.1), temporary towers will be erected. The purpose of the temporary towers is to provide support for the arch-rib as it is being constructed. CIBrE plans to use the temporary towers to mount instrumentation to and intends to instrument several temporary stays. The following sections outline CIBrE intentions for the instrumentation of the temporary towers and temporary stays.

7.6.1 South Temporary Tower

To quantify site-specific wind behavior, CIBrE will instrument the south temporary construction tower with anemometers. The anemometers will be placed at five different heights to help determine a wind velocity profile for the proposed site. CIBrE has not yet determined the final location of the anemometers.

It is intended that as the tower is constructed segmentally during Step 1 of the general construction sequence described in Section 7.3.1, the anemometers will be installed. All hardwire connections for the anemometers will be made by routing the sensor wires down the legs of the tower to the base station located near the base of the tower. The exact location of this base station has not yet been determined.

CIBrE and the contractor will work together to determine a suitable location for the anemometers and the base station enclosure based on the provided final design of the temporary towers.

Further installation details and procedure for anemometers can be found in Chapter 10 – Instrumentation.

7.6.2 Temporary Stays

To monitor the forces in the temporary support cables, CIBrE intends to instrument several temporary stays with load cells. The information gathered from the load cells will help CIBrE track the evolution of stresses in the arch as it is being constructed. The data will also help quantify the dead load stress before the bridge is open to traffic. CIBrE has not yet finalized the details regarding instrumentation of the temporary stays but will do so upon receiving the final design for the temporary tower. CIBrE will work with the contractor to determine which temporary stays will be instrumented and how the installation will be accomplished. Hardwire connections will be achieved similar to the anemometers, and all instrumentation will be connected to the base station located at the base of the temporary towers.

Further installation details and procedure for temporary load cells (and other equipment) can be found in Chapter 10 – Instrumentation.

7.7 Phase 4 - Back-Span Instrumentation

In addition to erecting the temporary towers and constructing the arch bases during Step 1 of the general construction sequence (Section 7.3.1), the back-spans will be erected. Erection of the back spans consists of erecting abutments, casting the central beam, and erecting the precast roadway sections. CIBrE intends to instrument the north and south abutment bearings and predetermined locations in the central beam and precast roadway segments. Due to the complexities of this phase of the project, a schedule was developed to organize the installation of all monitoring equipment. Figure 7.23 details this schedule.

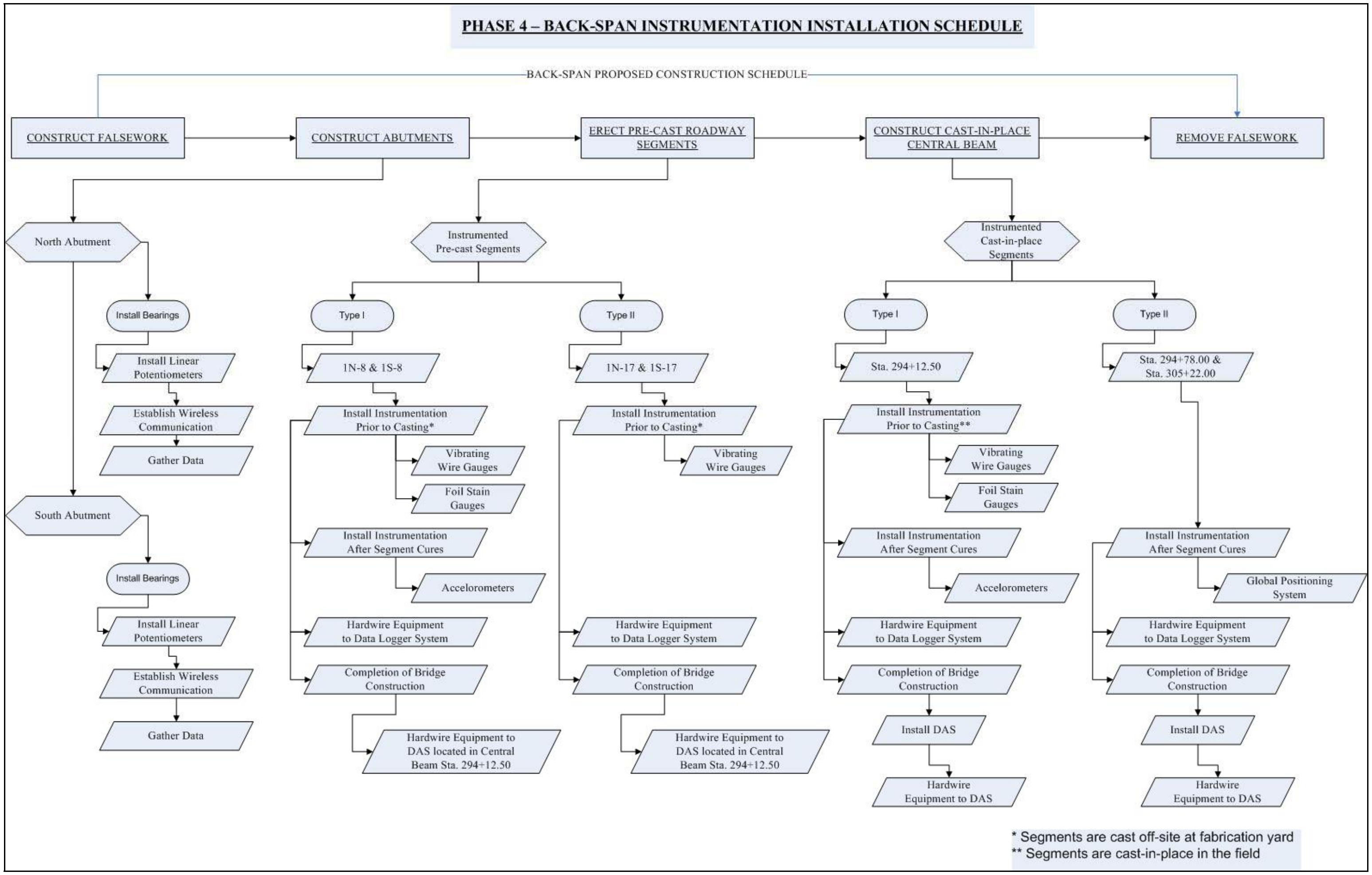

Figure 7.23 Back-Span Instrumentation Installation Schedule

7.7.1 Abutment Bearing Instrumentation

To monitor expansion and contraction of the bridge due to live load effects (thermal, wind, and ambient traffic), linear potentiometers will be installed. As described in Section 7.2.1, the north and south abutment bearings will be instrumented. Two linear potentiometers will be installed at each location. The following section outlines the intended instrumentation plan. Further details about each gauge type can be found in Chapter 10 – Instrumentation.

7.7.1.1 South and North Abutment Bearing Instrumentation

Both the north and south abutment bearings will be instrumented. There are two bearings at each location. Linear potentiometers will be installed at these locations. For the purpose of data communication, a wireless system will be installed when the linear potentiometers are installed. It is intended that no hardwiring will be necessary at these locations. CIBrE has not yet finalized a plan for the wireless communication of the collected data but will contact DelDOT and the contractor as soon as the information becomes available. Figure 7.24 details the location of the linear potentiometers.

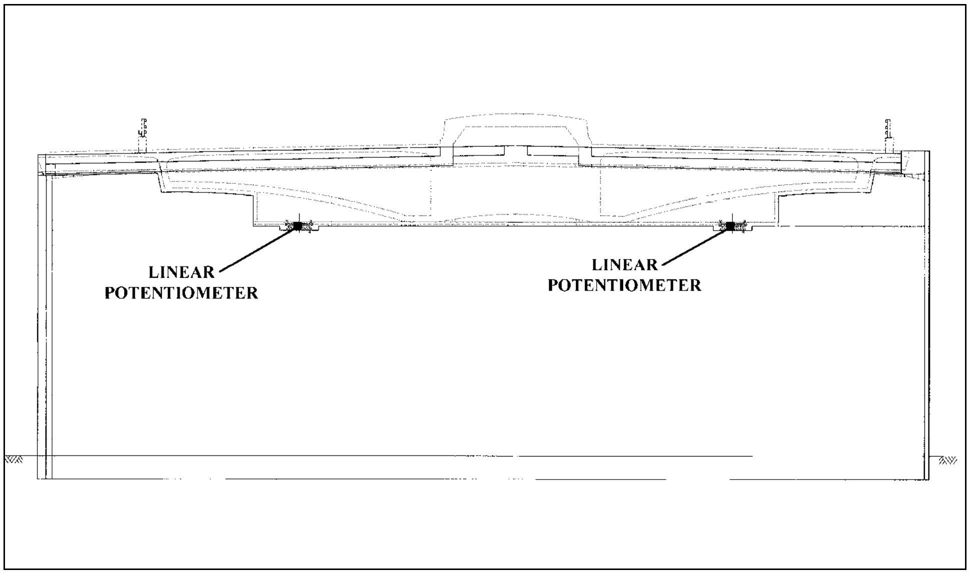

Figure 7.24 Abutment Bearing Linear Potentiometer Locations (North and South Abutment) (Modified IRIB Specifications and Construction Plans)

7.7.2 Precast Northbound and Southbound Roadway Segments

Monitoring equipment will be installed in the northbound and southbound roadway sections to capture various load effects. As described in Section 7.2.1, a total of four segments will be instrumented. All instrumented segments will be located on the south side of the bridge. Various combinations of vibrating wire gauges, foil strain gauges, and accelerometers will be installed. The following sections outline the different types of sections that will be instrumented with the various monitoring equipment. Further details about each gauge type can be found in Chapter 10 – Instrumentation.

7.7.2.1 Type-I

Precast Roadway Type-I segments are located at 1N-8 and 1S-8. There will be four vibrating wire gauges, four foil strain gauges, and one accelerometer installed in each segment. Additionally, one data logger will be installed during construction to capture monitoring data. To accommodate permanent data acquisition, through-holes have been provided so that gauge wire can be run from the block-out to the data acquisition system located in the central beam. Figure 7.25 details the location of all permanent equipment that will be installed within Type-I. Figure 7.26 further details the schedule for Type-I instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor. Also, exact locations of the “block-out” will need to be determined.

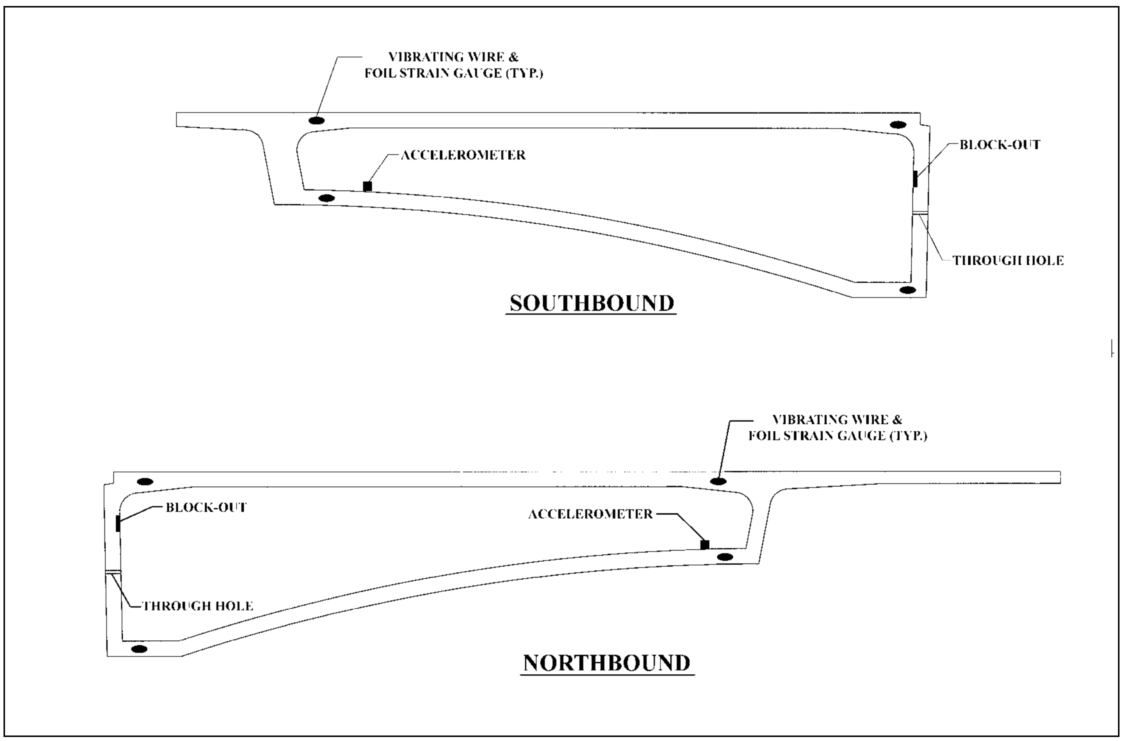

Figure 7.25 Roadway Segments Type-I Gauge Locations (Modified IRIB Specifications and Construction Plans)

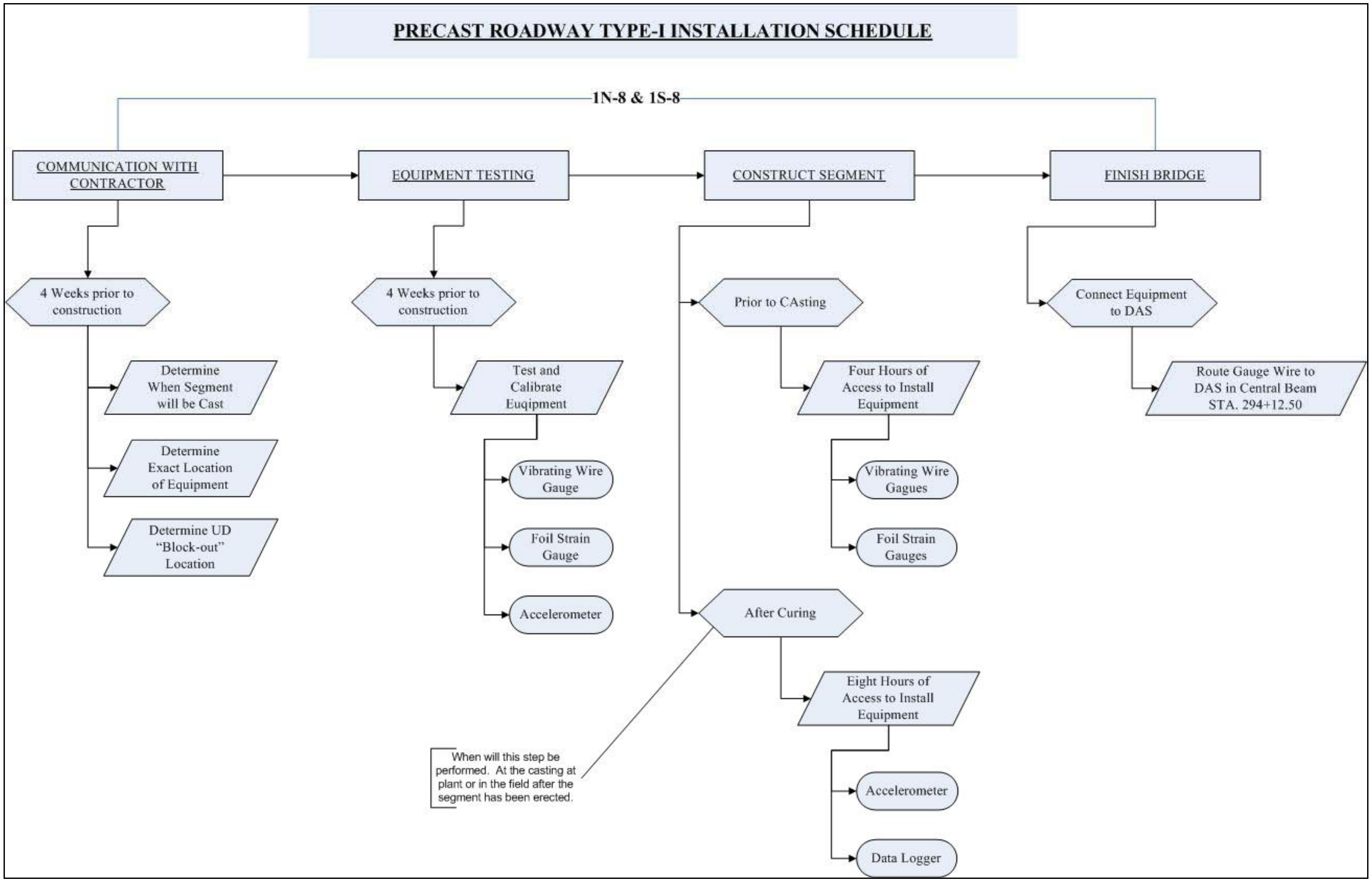

Figure 7.26 Precast Roadway Type-I Installation Schedule

7.7.2.2 Type-II

Precast Roadway Type-II segments are located at 1N-17 and 1S-17. There will be four vibrating wire gauges installed. Additionally, one data logger will be installed during construction to capture monitoring data. To accommodate permanent data acquisition, through-holes have been provided so that gauge wire can be run from the block-out to the data acquisition system located in the central beam. Figure 7.27 details the location of all permanent equipment that will be installed within Type-II. Figure 7.28 further details the schedule for Type-II instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor. Also, exact locations of the "block-out" will need to be determined.

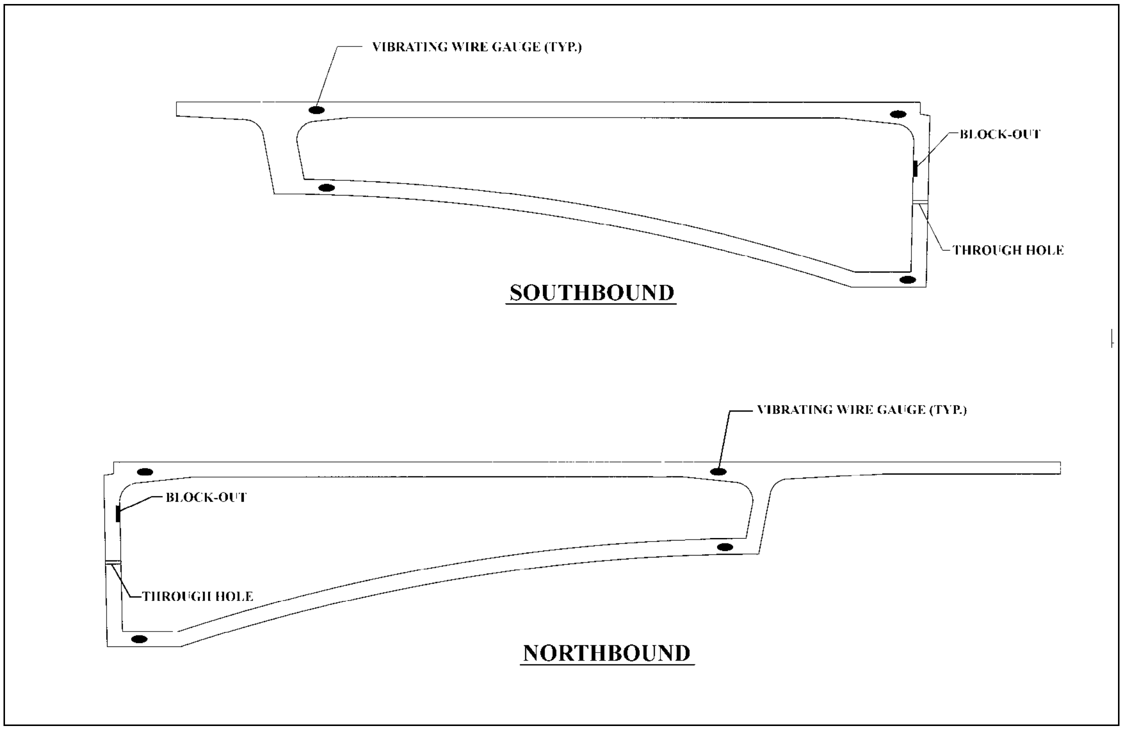

Figure 7.27 Roadway Segments Type-II Gauge Locations (Modified IRIB Specifications and Construction Plans)

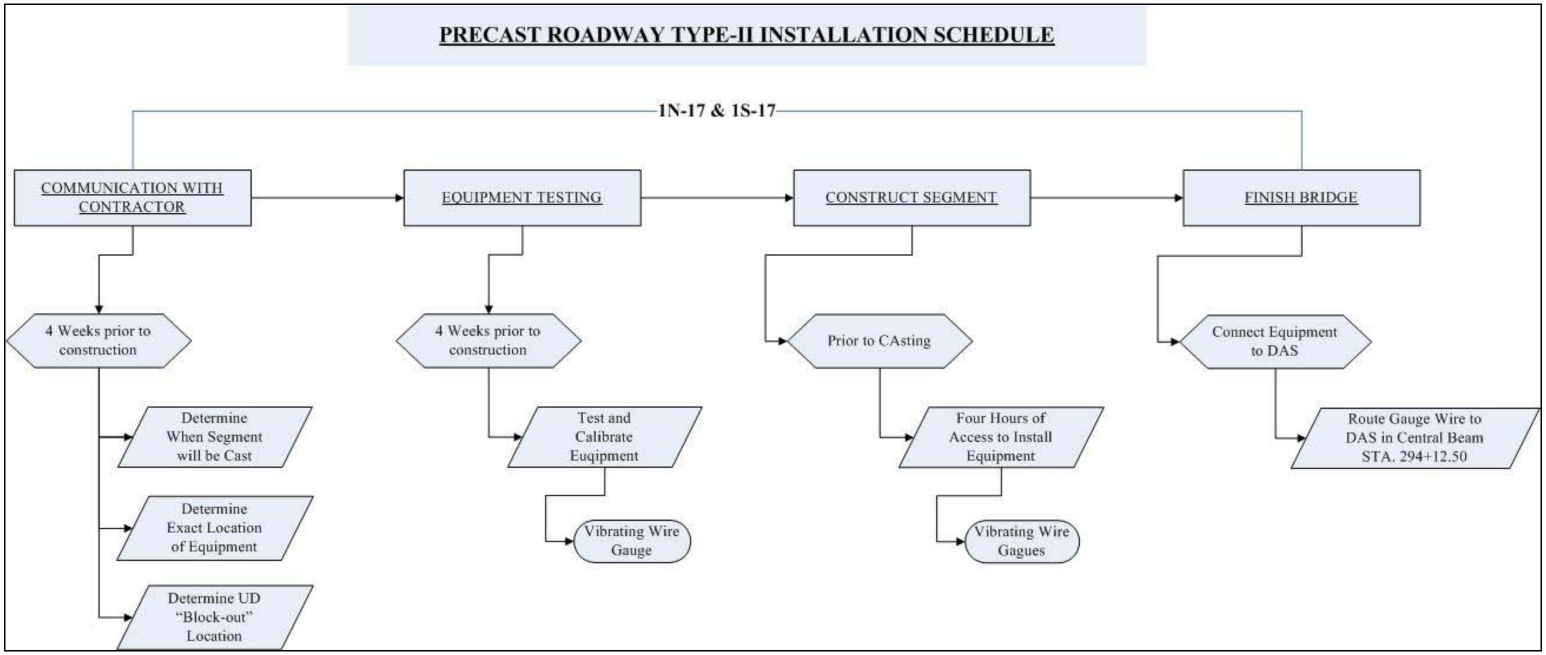

Figure 7.28 Precast Roadway Type-II Installation Schedule

7.7.3 Cast-In-Place Central Beam Segments

To capture load effects in the central beam, monitoring equipment will be installed. As described in Section 7.2.1, there will be a total of three segments instrumented in the central beam. Two of the segments will be located on the south side of the bridge and one on the north side. Various combinations of vibrating wire gauges, foil strain gauges, accelerometers, and global positioning systems will be installed at predetermined locations in the central beam. The following sections outline the various types of sections that will be instrumented with monitoring equipment. Further details about the each gauge type can be found in Chapter 10 – Instrumentation.

7.7.3.1 Type-I

Central Beam Type-I segment is located at Sta. 294+12.50. There will be four vibrating wire gauges, four foil strain gauges, and one accelerometer. Additionally, one data logger will be installed during construction, and one data acquisition system will be installed once construction is complete. Figure 7.29 details the location of all permanent equipment that will be installed. Figure 7.30 further details the schedule for Type-I instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor.

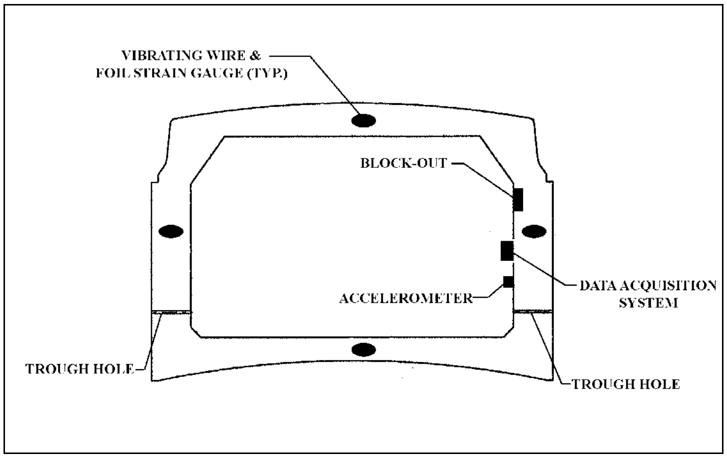

Figure 7.29 Central Beam Type-I Gauge Locations (Modified IRIB Specifications and Construction Plans)

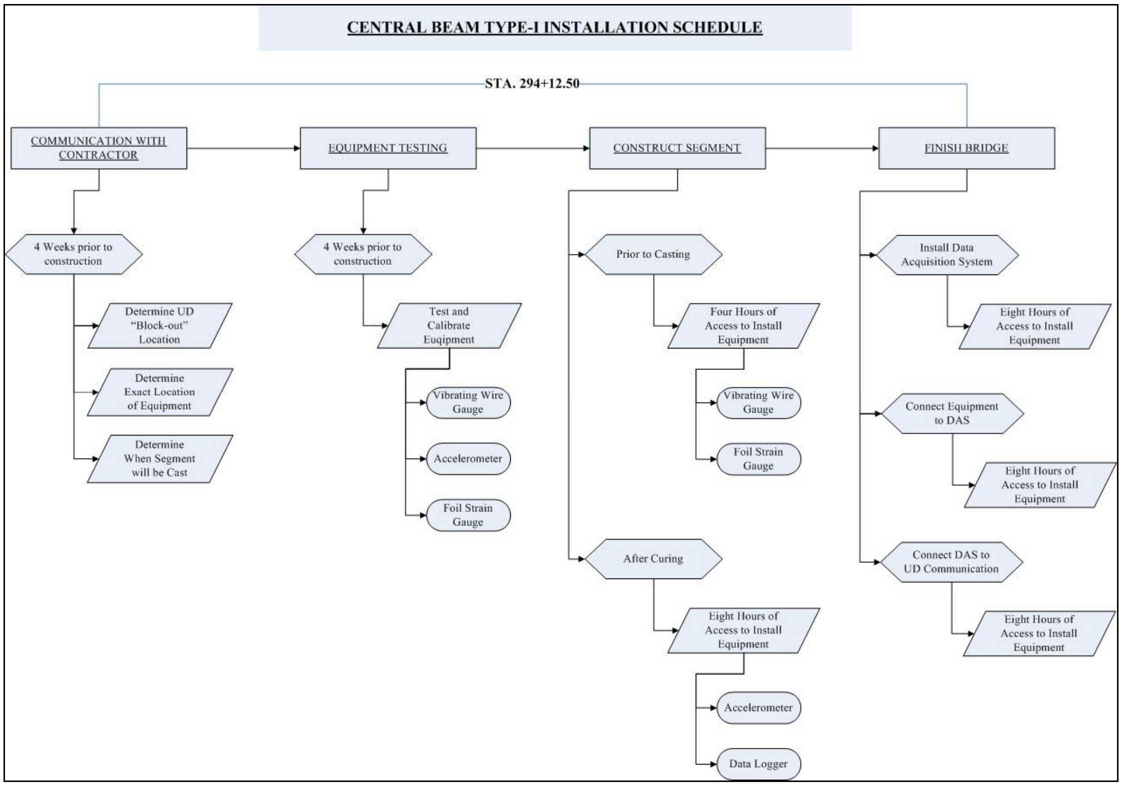

Figure 7.30 Central Beam Type-I Installation Schedule

7.7.3.2 Type-II

Central Beam Type-II segments are located at Sta. 294+78.00 and 305+22.00. There will be one global positioning system installed at these locations. Additionally, one data logger will be installed during construction, and one data acquisition system will be installed once construction is complete. Figure 7.31 details the location of all permanent equipment that will be installed within Type-II. Figure 7.32 further details the schedule for Type-II instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor.

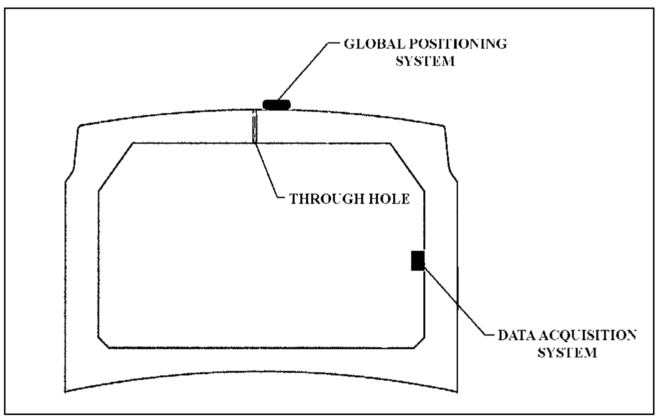

Figure 7.31 Central Beam Type-II Gauge Locations (Modified IRIB Specifications and Construction Plans)

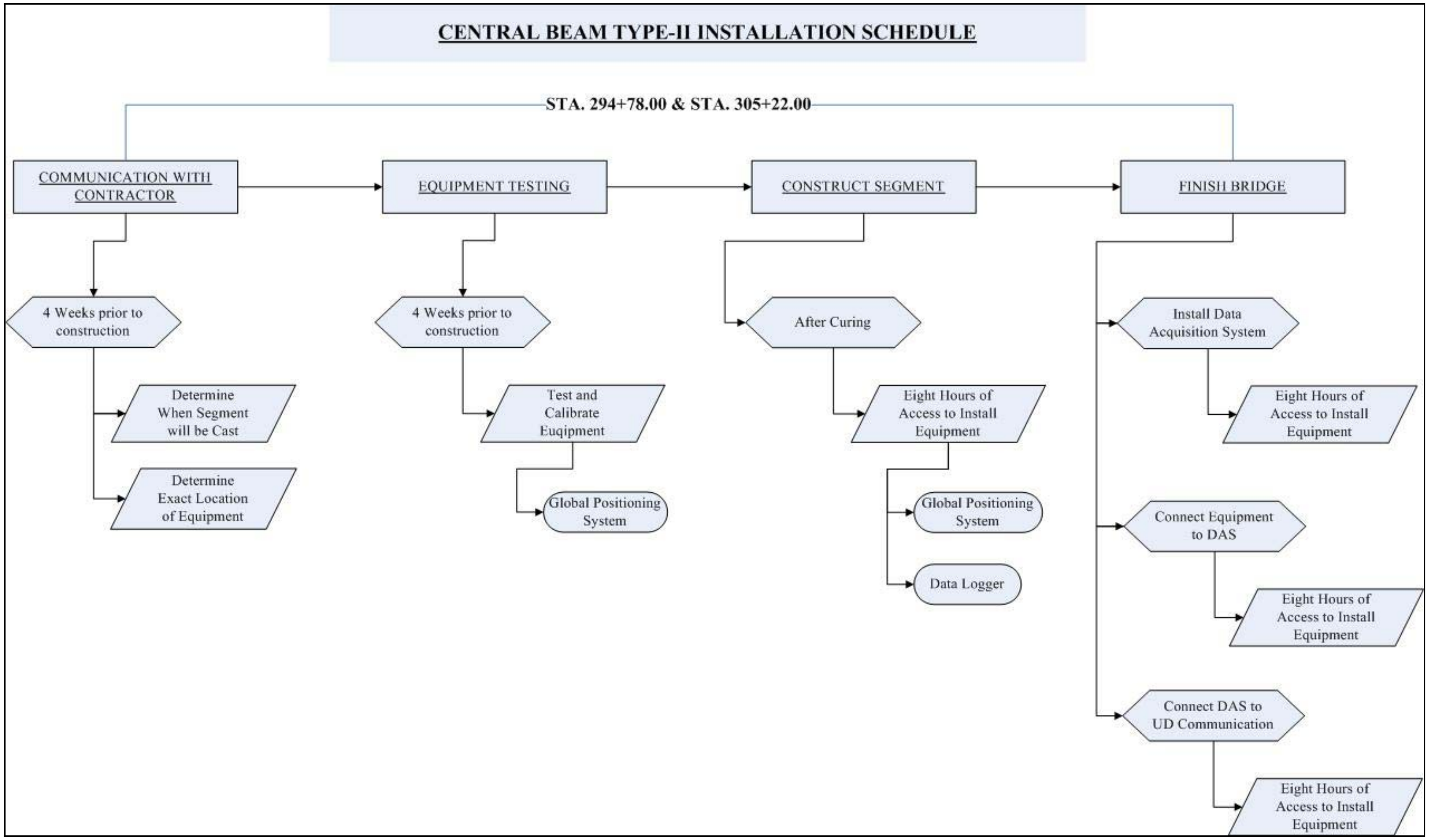

Figure 7.32 Central Beam Type-II Installation Schedule

7.8 Phase 5 - Arch-Rib Instrumentation

During Step 2 of the general construction sequence described in Section 7.3.1, the arch-rib will cast-in-place using a form-traveler and supported throughout construction with temporary stays. Both the Upstation and Downstation portions of the bridge will be constructed at the same time. CIBrE plans to instrument twelve locations in the arch-rib (seven locations Upstation and five locations Downstation). Each location will consist of a variety of gauges. A complete schedule of the arch-rib construction and the intended instrumentation procedures are described in Figures 7.33 and 7.34. Figure 7.33 describes the proposed construction sequence of the arch-rib while, Figure 7.34 gives a general outline of the schedule for each type of arch segment that will be instrumented.

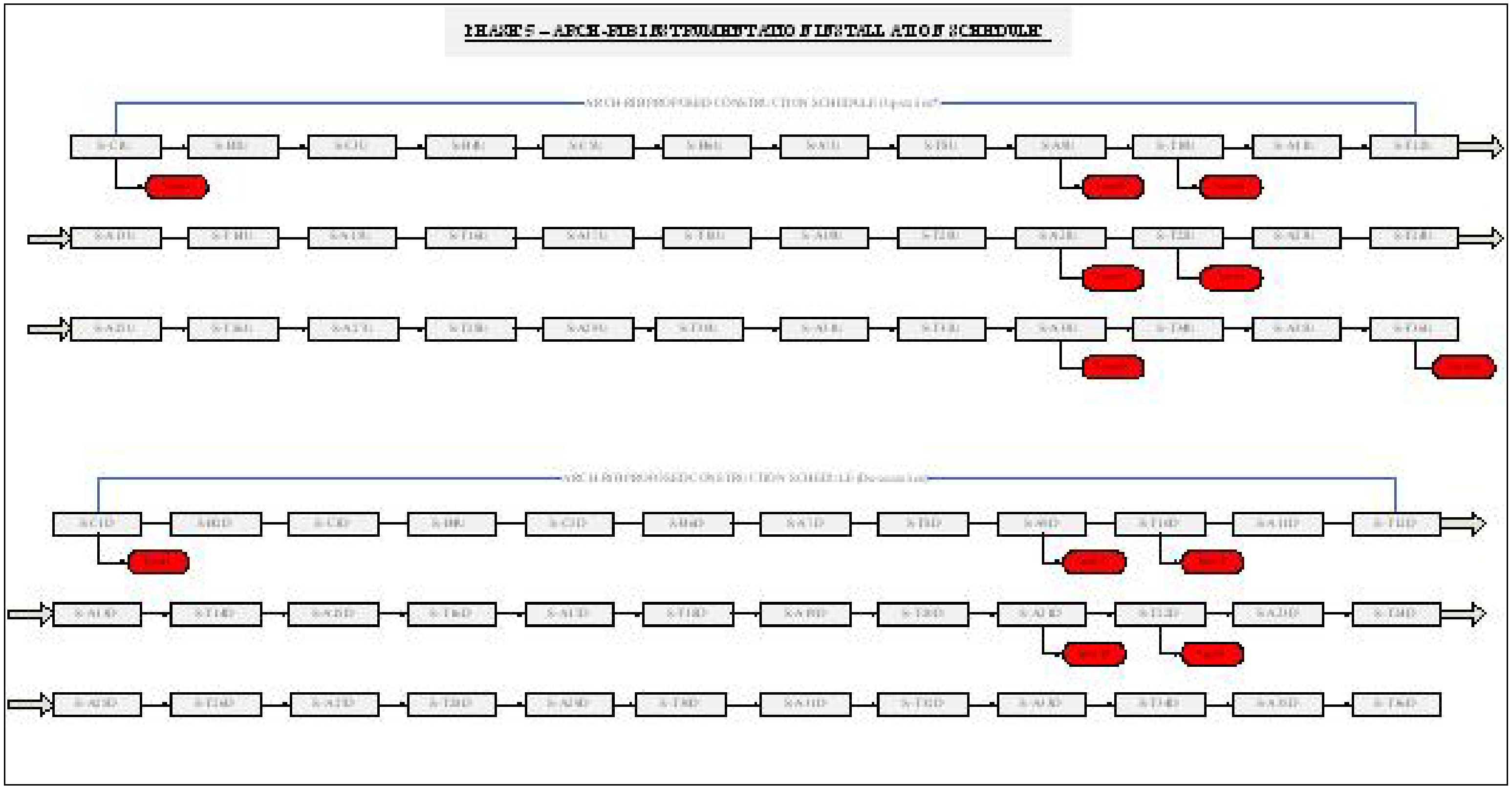

Figure 7.33 Arch-Rib Instrumentation Installation Schedule

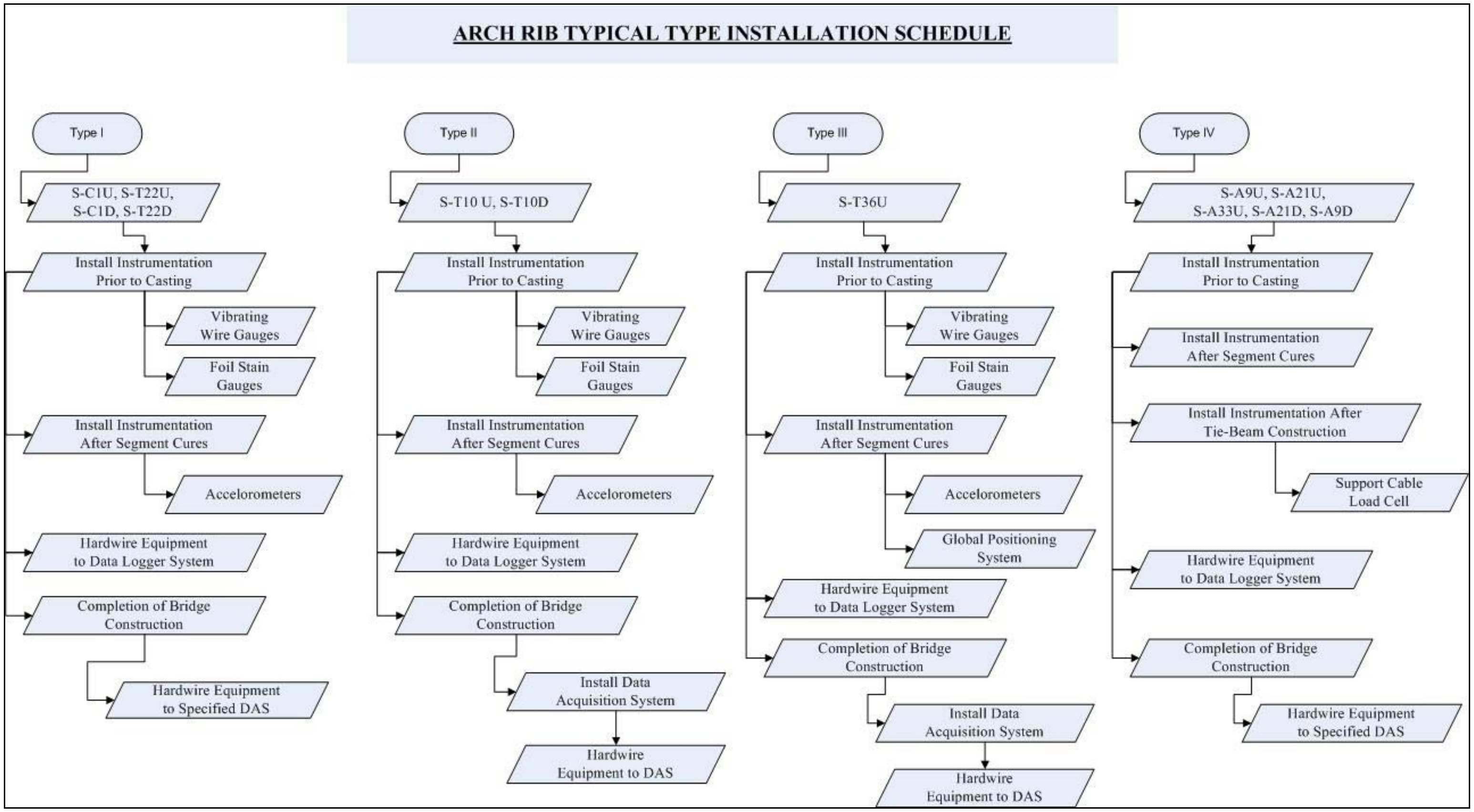

Figure 7.34 Arch-Rib Typical Type Installation Schedule

7.8.1 Cast-In-Place Arch-Rib Segments

Twelve sections along the arch-rib will be instrumented with monitoring equipment to capture load effects. Various combinations of vibrating wire gauges, foil strain gauges, accelerometers, load cells, and global positioning systems will be installed. The following sections outline the various types of sections that will be instrumented with monitoring equipment. Further details about each gauge type can be found in Chapter 10 – Instrumentation.

7.8.1.1 Type-I

Arch-Rib Type-I segments are located at S-C1U, S-T22U, S-C1D, and S-T22D. There will be four vibrating wire gauges, four foil strain gauges, and one accelerometer. Additionally, one data logger will be installed during construction to capture monitoring data. Permanent data acquisition will be accomplished by routing gauge wire from the block-out through contractor-installed local conduit to a location in the arch-rib which contains a data acquisition system. Please see Section 7.2.3.1 for further details. Figure 7.35 details the location of all permanent equipment that will be installed within Type-I. Figure 7.36 further details the schedule for Type-I instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor. Also, exact locations of the “block-out” will need to be determined.

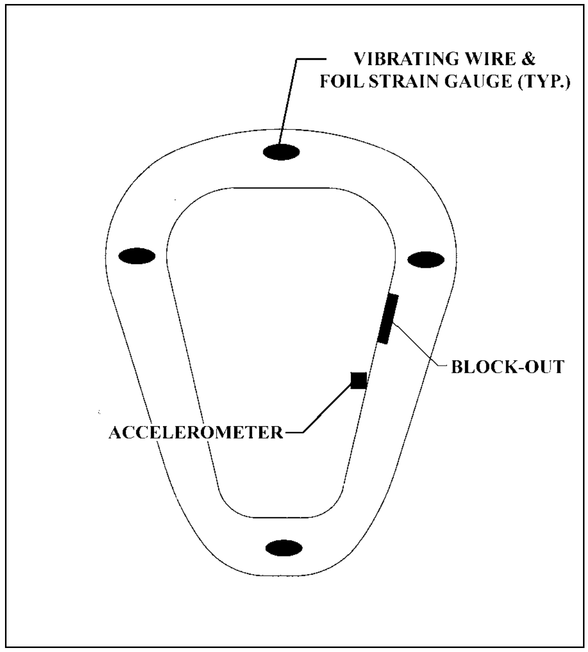

Figure 7.35 Arch-Rib Type-I Gauge Locations (Modified IRIB Specifications and Construction Plans)

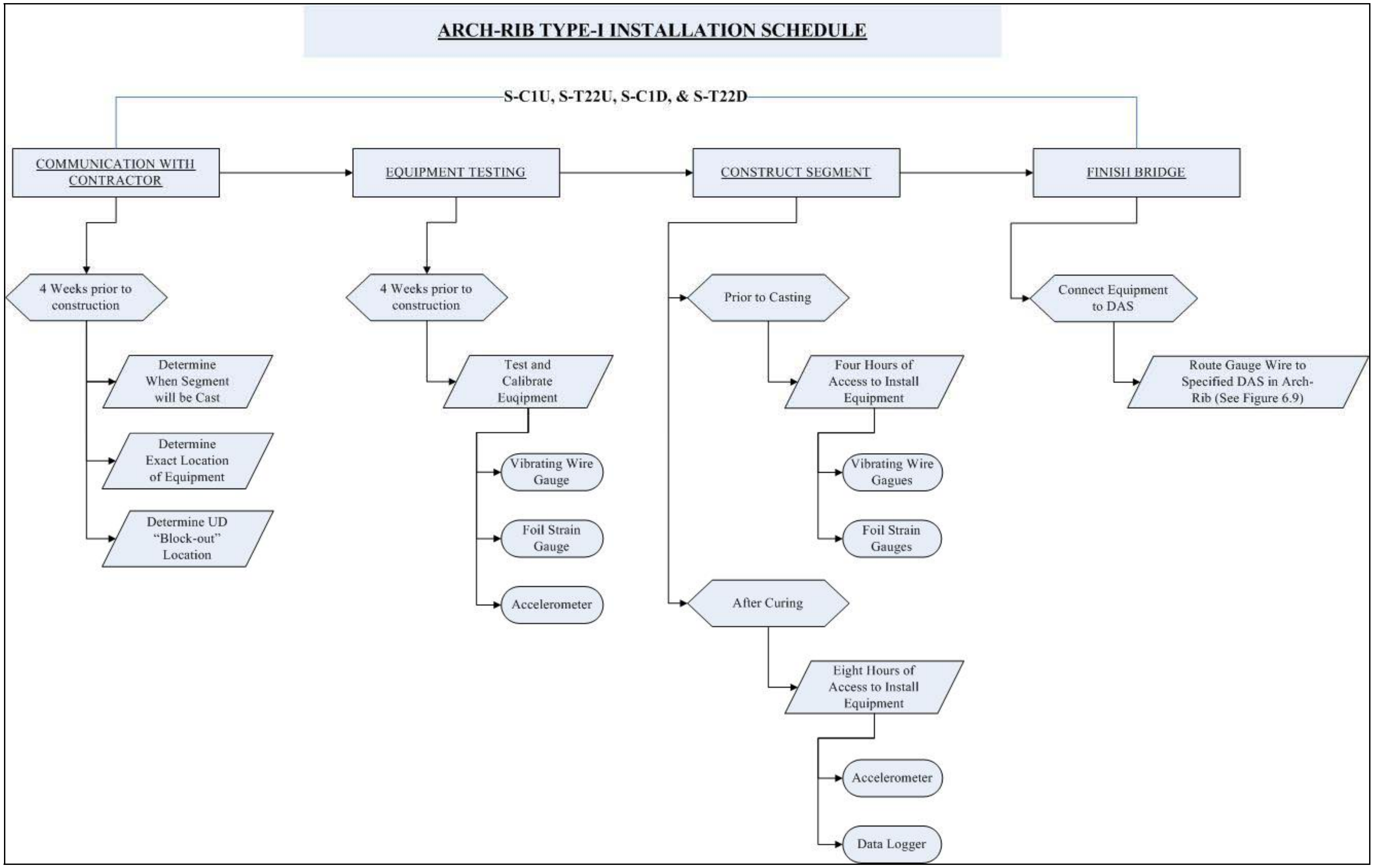

Figure 7.36 Arch-Rib Type-I Installation Schedule

7.8.1.2 Type-II

Arch-Rib Type-II segments are located at S-T10U and S-T10D. There will be four vibrating wire gauges, four foil strain gauges, and one accelerometer. Additionally, one data logger will be installed during construction, and one data acquisition system will be installed once construction is complete. Permanent data acquisition will be accomplished by routing gauge wire from the block-out through contractor-installed local conduit to a location in the arch-rib which contains a data acquisition system. Please see Section 7.2.3.1 for further details. Figure 7.37 details the location of all permanent equipment that will be installed within Type-II. Figure 7.38 further details the schedule for Type-II instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor. Also, exact locations of the "block-out" will need to be determined.

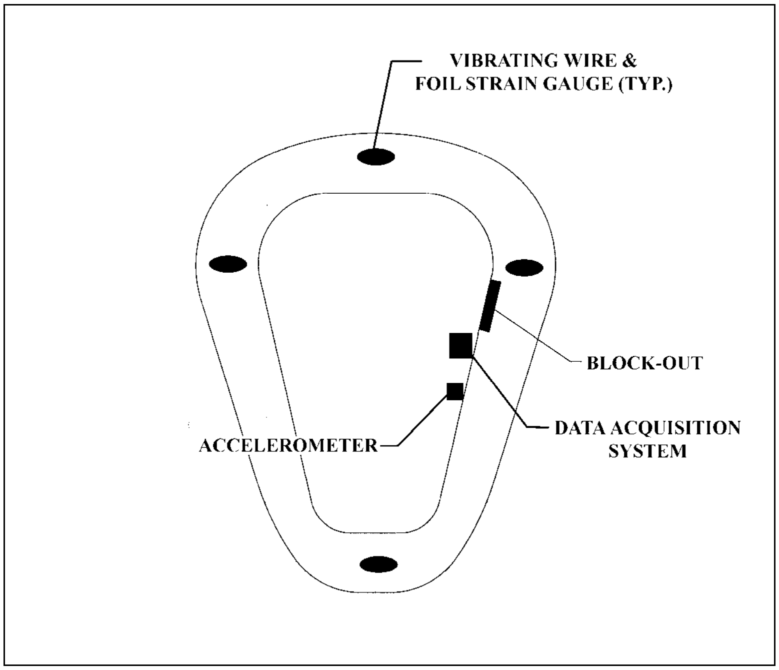

Figure 7.37 Arch-Rib Type-II Gauge Locations (Modified IRIB Specifications and Construction Plans)

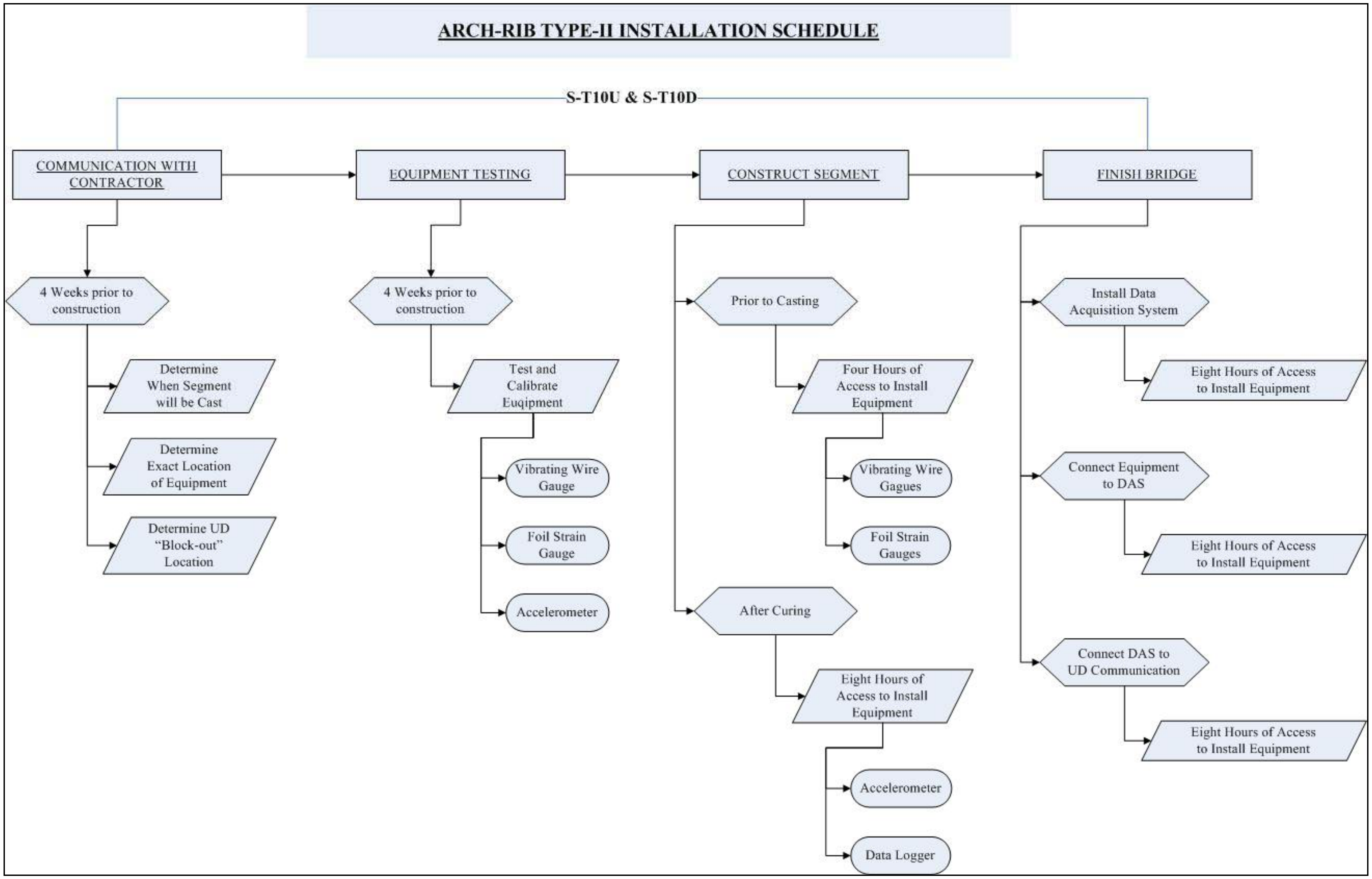

Figure 7.38 Arch-Rib Type-II Installation Schedule

7.8.1.3 Type-III

Arch-Rib Type-III segment is located at S-T36U. There will be four vibrating wire gauges, four foil strain gauges, one accelerometer, and one global positioning system installed. Additionally, one data logger will be installed during construction, and one data acquisition system will be installed once construction is complete. Permanent data acquisition will be accomplished by routing gauge wire from the block-out through contractor-installed local conduit to a location in the arch-rib which contains a data acquisition system. Please see Section 7.2.3.1 for further details. Figure 7.39 details the location of all permanent equipment that will be installed within Type-III. Figure 7.40 further details the schedule for Type-III instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor. Also, exact locations of the "block-out" will need to be determined.

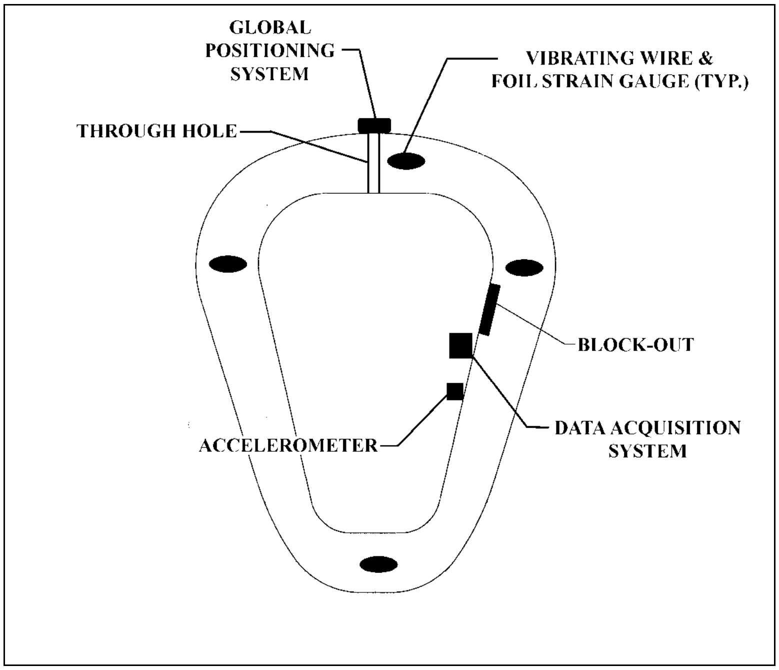

Figure 7.39 Arch-Rib Type-III Gauge Locations (Modified IRIB Specifications and Construction Plans)

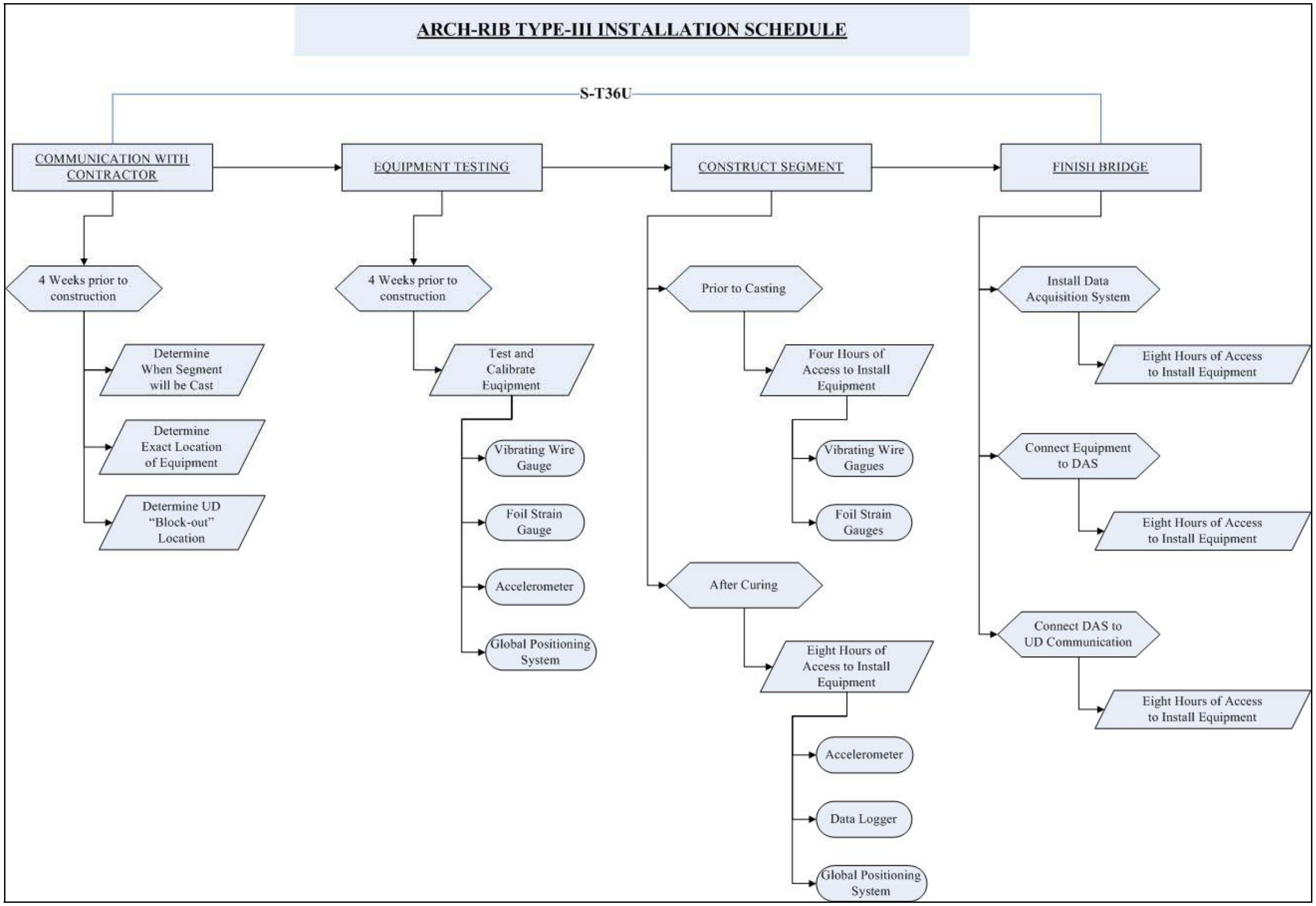

Figure 7.40 Arch-Rib Type-III Installation Schedule

7.8.1.4 Type-IV

Arch-Rib Type-IV segments are located at S-A9U, S-A21U, S-A33U, S-A21D, and S-A9D. There will be one load cell installed. Additionally, one data logger will be installed during construction to capture monitoring data. Permanent data acquisition will be accomplished by routing gauge wire from the block-out through contractor-installed local conduit to a location in the arch-rib which contains a data acquisition system. Please see Section 7.2.3.1 for further details. Figure 7.41 details the location of all permanent equipment that will be installed within Type-IV. Figure 7.42 further details the schedule for Type-IV instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor. Also, exact locations of the "block-out" will need to be determined.

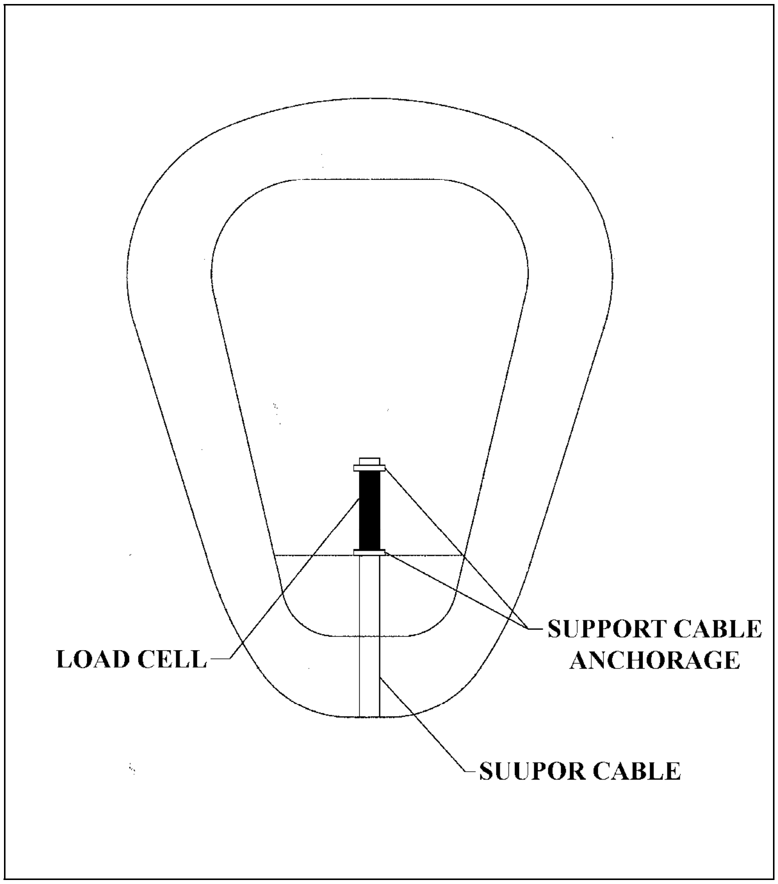

Figure 7.41 Arch-Rib Type-IV Gauge Locations (Modified IRIB Specifications and Construction Plans)

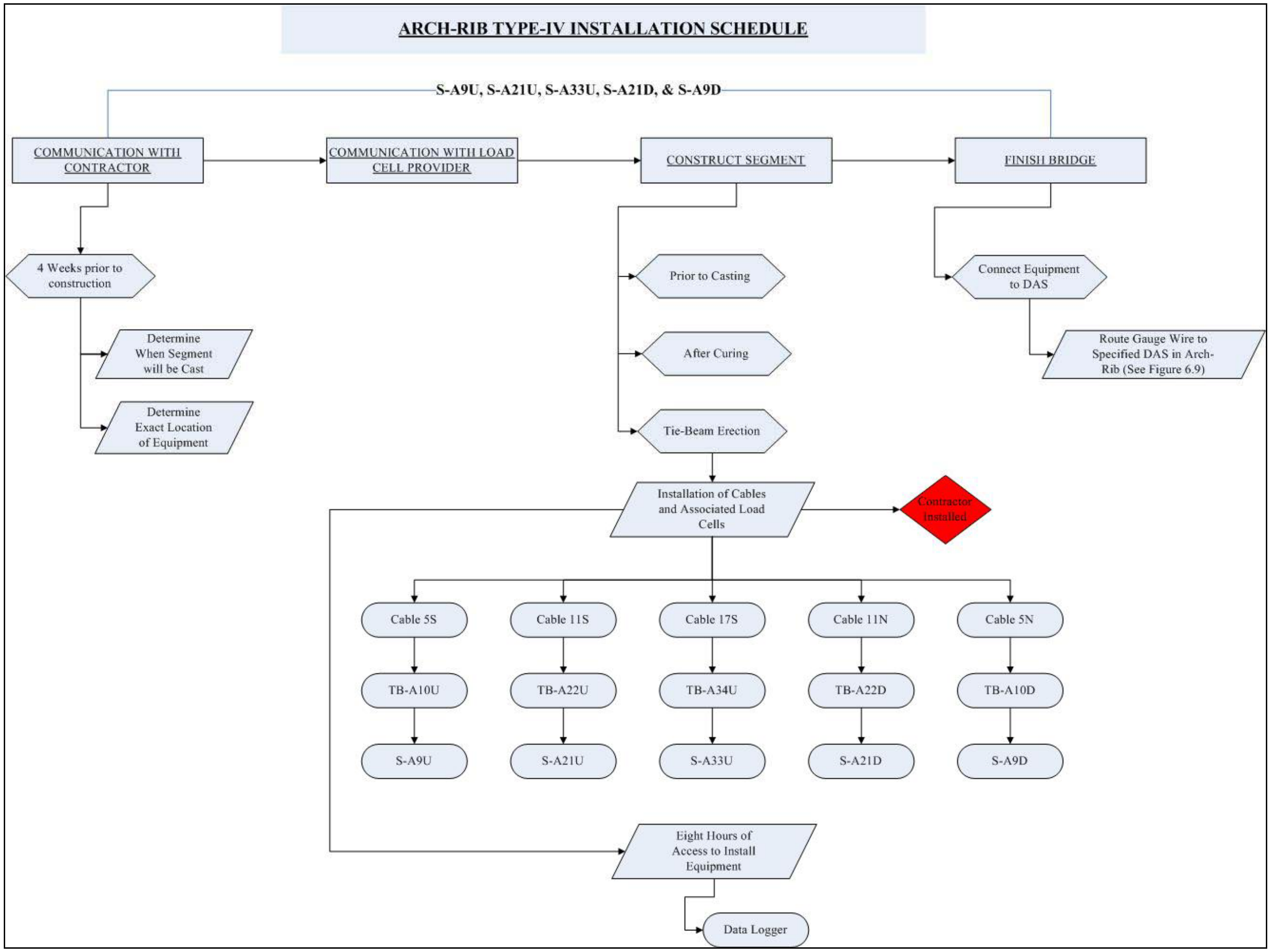

Figure 7.42 Arch-Rib Type-IV Installation Schedule

7.9 Phase 6 - Tie-Beam Instrumentation

During Step 4 of the general construction sequence described in Section 7.3.1 the tie-beam will be cast-in-place using a form-traveler. Both the Upstation and Downstation portions of the bridge will be constructed at the same time. CIBrE plans to instrument five locations in the tie-beam (three locations Upstation and two locations Downstation). Each location will consist of a variety of gauges. A complete schedule of the tie-beam construction and the intended instrumentation procedures is described in Figure 7.43.

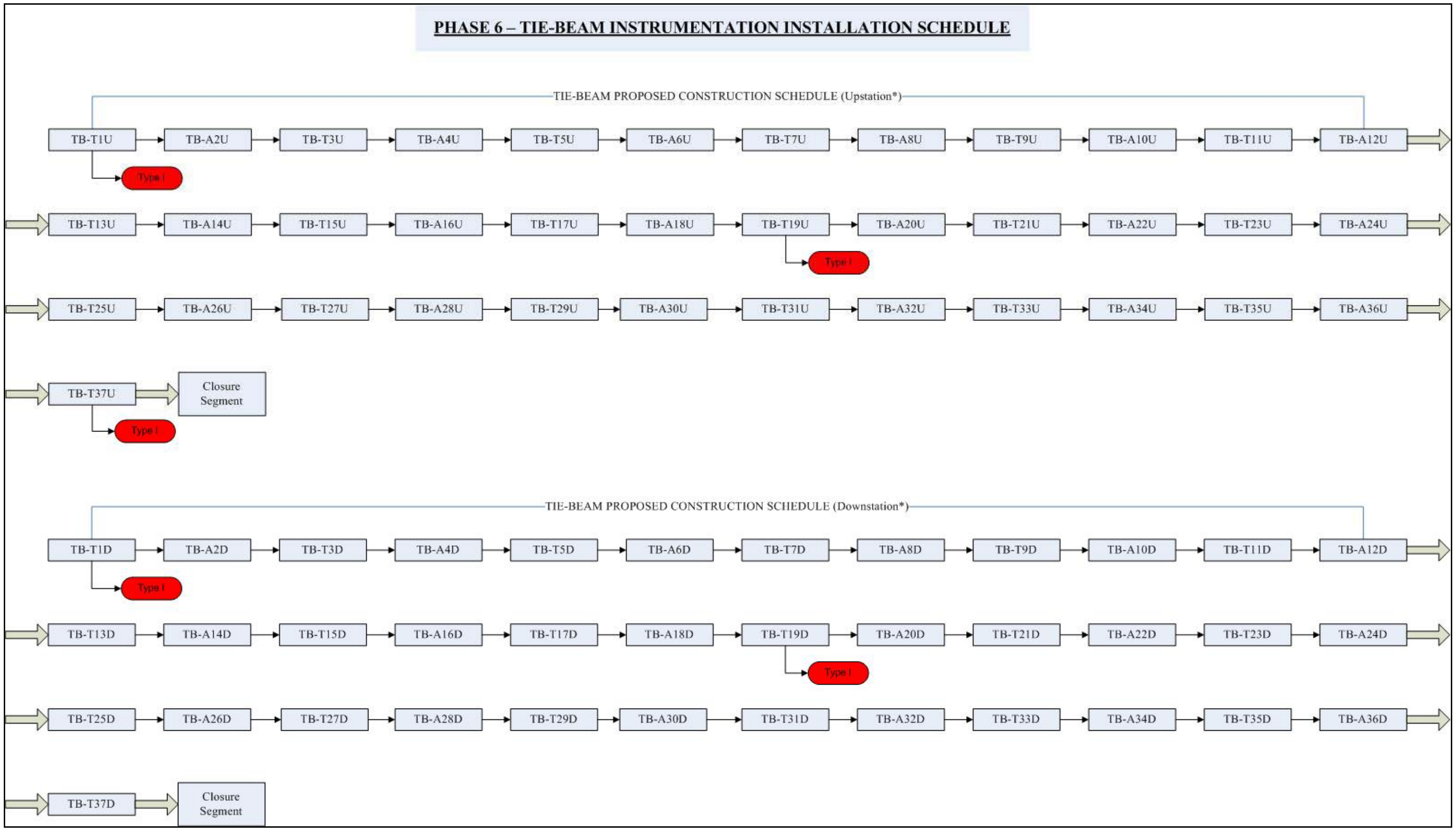

Figure 7.43 Tie-Beam Instrumentation Installation Schedule

7.9.1 Cast-In-Place Tie-Beam Segments

Five sections along the tie-beam will be instrumented with monitoring equipment to capture load effects. Various combinations of vibrating wire gauges, foil strain gauges, accelerometers, load cells, and global positioning systems will be installed. The following sections outline the various types of sections that will be instrumented with monitoring equipment. Further details about each gauge type can be found in Chapter 10 – Instrumentation.

7.9.1.1 Type-I

Tie-Beam Type-I segments are located at TB-T1U, TB-T19U, TB-T37U, TB-T19D, TB-T1D. There will be four vibrating wire gauges, four foil strain gauges, and one accelerometer installed at each location. Additionally, one data logger will be installed during construction, and one data acquisition system will be installed once construction is complete. Figure 7.44 details the location of all permanent equipment that will be installed within Type-I. Figure 7.45 further details the schedule for Type-I instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor. Also, exact locations of the "block-out" will need to be determined.

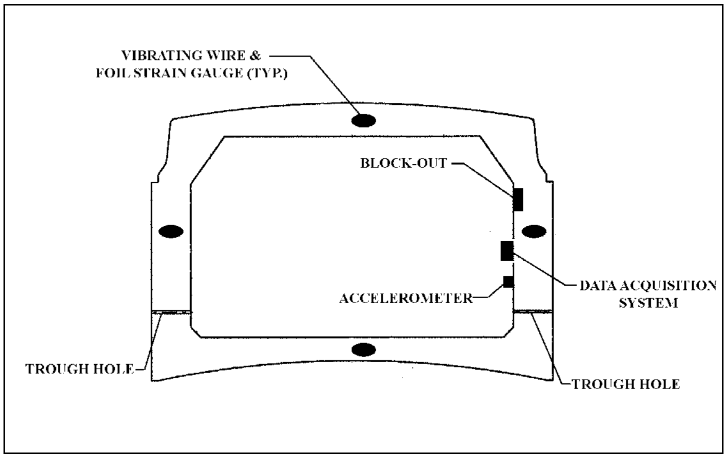

Figure 7.44 Tie-Beam Type-I Gauge Locations (Modified IRIB Specifications and Construction Plans)

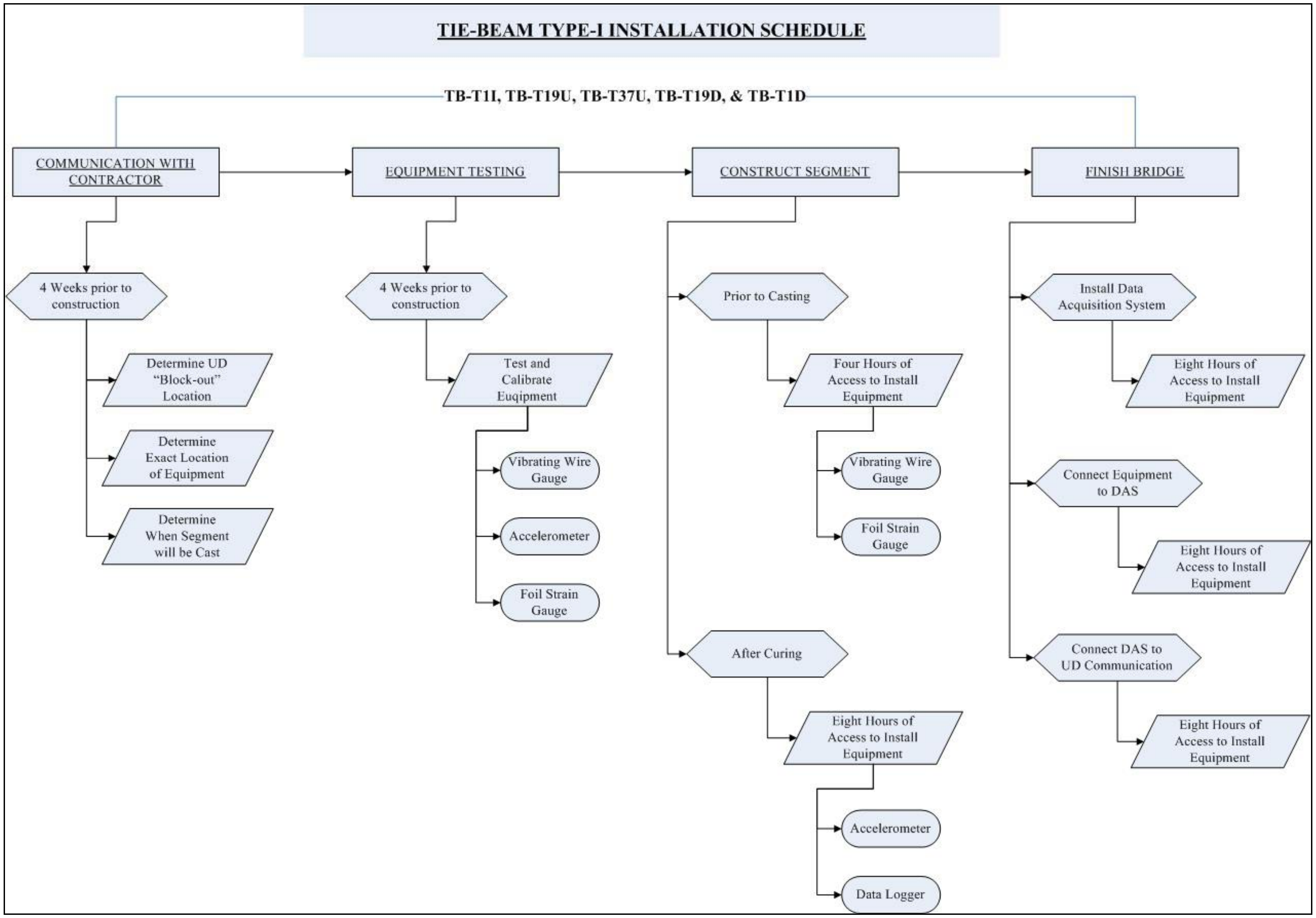

Figure 7.45 Tie-Beam Type-I Installation Schedule

7.9.2 Post-Tensioning Tendons

CIBrE intends to instrument void detection equipment in three post-tensioning tendons located in the tie-beam. CIBrE has not yet determined which post-tensioning tendons will be instrumented with void detection equipment. The instrumentation involves pulling a thin monitoring wire through the ducts along with the post-tensioning strands. The wire will require a separate access hole in the anchorage end plate. To demonstrate the installation of the tendon void detection system, and provide calibration, the same system will be installed in the clear ducts used to demonstrate the grouting techniques. CIBrE will contact the contractor and DelDOT when the all details of the void detection system have been finalized.

7.10 Phase 7 – Northbound and Southbound Roadway Instrumentation

During Step 6 of the general construction sequence described in Section 7.3.1, the northbound and southbound roadway segments will be erected. Both the Upstation and Downstation portions of the bridge will be erected at the same time. CIBrE plans to instrument five locations each in the northbound and southbound roadway segments (three locations Upstation and two locations Downstation). Each location will consist of a variety of gauges. A complete schedule of the roadway erection and the intended instrumentation procedures are described in Figures 7.46 and 7.47.

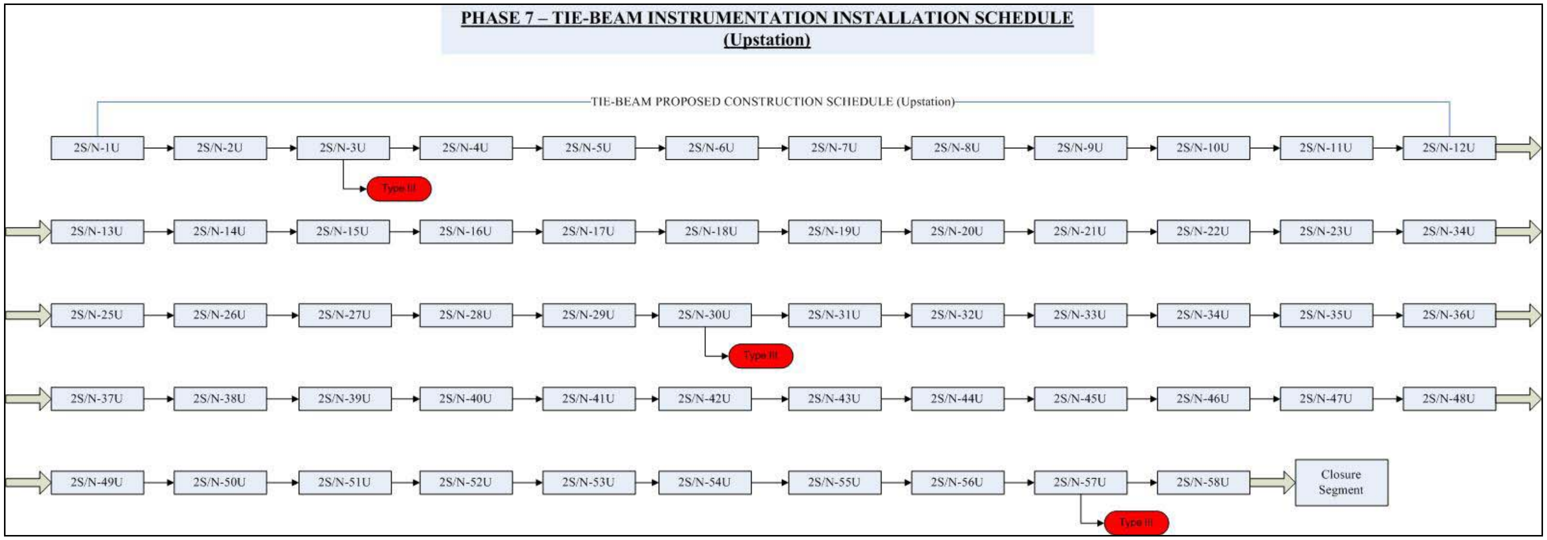

Figure 7.46 Roadway Instrumentation Installation Schedule (Upstation)

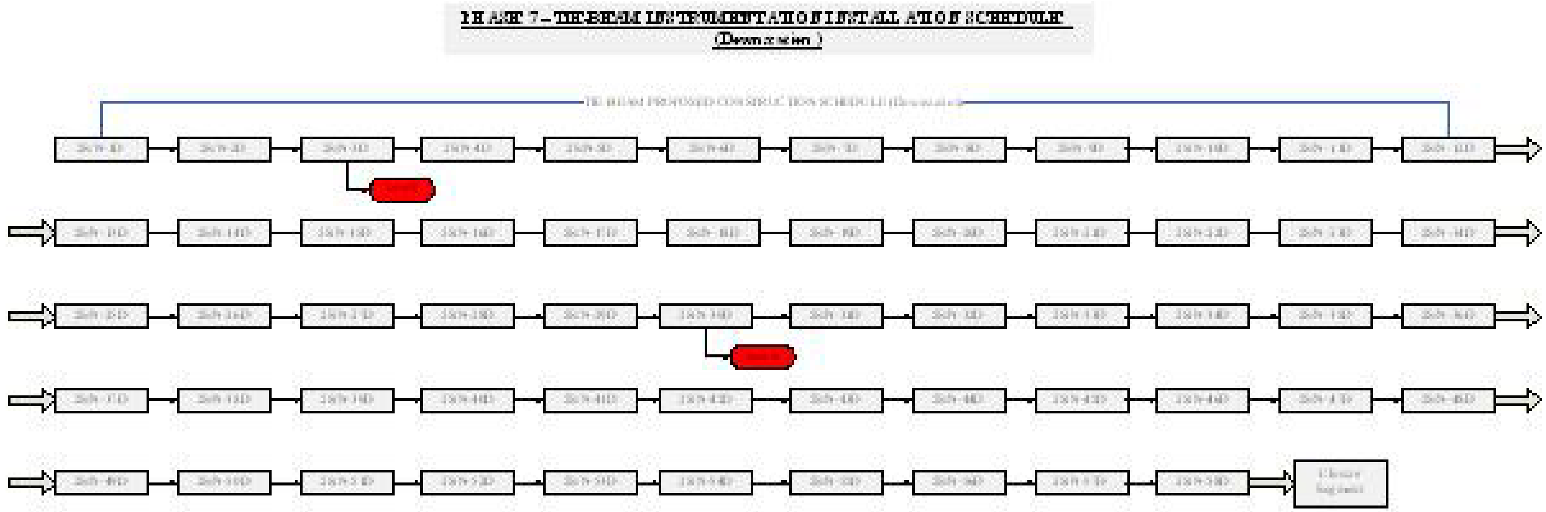

Figure 7.47 Roadway Instrumentation Installation Schedule (Downstation)

7.10.1 Precast Roadway Segments

Five sections each in the north and southbound roadway sections will be instrumented with monitoring equipment to capture load effects. Various combinations of vibrating wire gauges, foil strain gauges, and accelerometers will be installed. The following sections outline the different types of sections that will be instrumented with monitoring equipment. Further details about each gauge type can be found in Chapter 10 – Instrumentation.

7.10.1.1 Type-III

Precast Roadway Type-III segments are located at 2N-3U, 2S-3U, 2N-30U, 2S-30U, 2N-57U, 2S-57U, 2N-30D, 2S-30D, 2N-3D, 2S-3D. Four vibrating wire gauges, four foil strain gauges, and one accelerometer will be installed at each location. Additionally, one data logger will be installed during construction to capture monitoring data. To accommodate permanent data acquisition, through-holes have been provided so that gauge wire can be run from the block-out to the data acquisition system located in the tie-beam. Figure 7.48 details the location of all permanent equipment that will be installed within Type-III. Figure 7.49 further details the schedule for Type-III instrumentation installation and required hardwire connections. Exact locations of the monitoring equipment will need to be discussed with the contractor. Also, exact locations of the "block-out" will need to be determined.

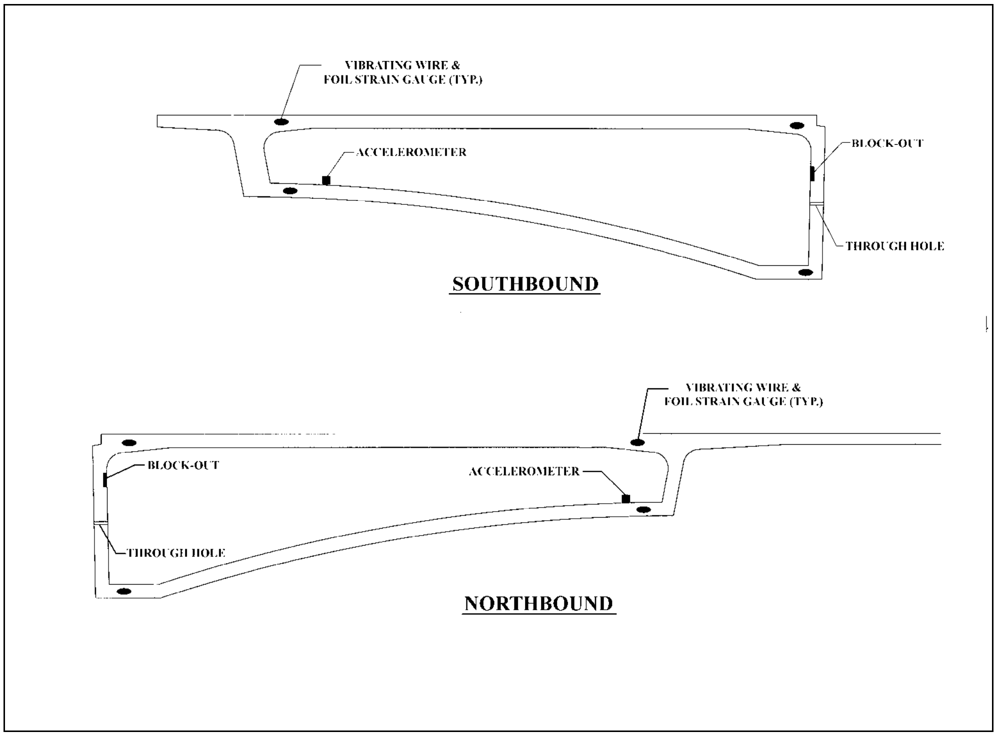

Figure 7.48 Precast Roadway Segments Type-I Gauge Locations (Modified IRIB Specifications and Construction Plans)

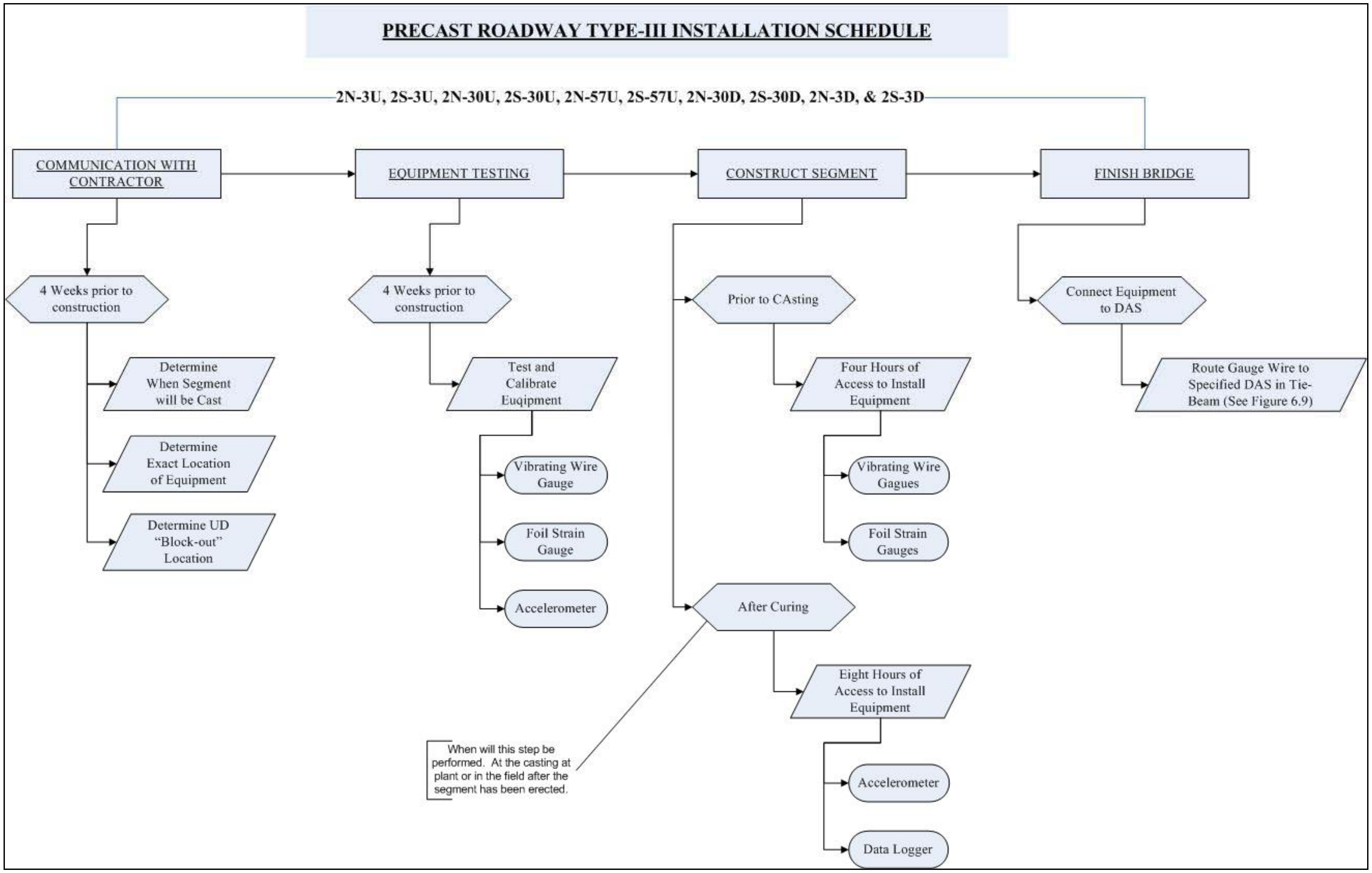

Figure 7.49 Precast Roadway Type-III Installation Schedule

7.10.2 Post-Tensioning Tendons

CIBrE intends to instrument void detection equipment in six post-tensioning tendons in the precast roadway segments; exact locations have not yet been determined. The instrumentation involves pulling a thin monitoring wire through the ducts along with the post-tensioning strands. The wire will require a separate access hole in the anchorage end plate. To demonstrate the installation of the tendon void detection system and provide calibration, the same system will be installed in the clear ducts used to demonstrate the grouting techniques. CIBrE will contact the contractor and DelDOT when the details of the void detection system have been finalized.

CHAPTER 8

STAGE IV – BASELINE BEHAVIOR

8.1 Introduction

During Stage IV of the monitoring project, CIBrE intends to capture the baseline behavior of the bridge, including initial geometry and behavior with respect to traffic, wind, and thermal loading. The information will be used to create a database to serve as a reference for DelDOT throughout the service life of the bridge. It is intended that this stage of the project will last no more that one year after the completion of the bridge. CIBrE will perform tests on the bridge before the bridge is open to construction and during its first year of service. The following sections outline the necessary tests that will be performed to help CIBrE quantify the behavior of the bridge under various loading conditions.

8.2 Initial Geometry

Geometry of the bridge will be continuously monitored through the use of three global positioning systems placed on the bridge (see Section 7.2.1 for exact location of GPS units). The initial geometry will be determined with these GPS units. A baseline temperature should also be determined.

Currently, CIBrE has no plans to capture the geometry in more detail. If CIBrE or DelDOT decides that more geometry data is necessary or desired than a detailed plan and schedule of the required tests should be laid out by CIBrE.

8.3 Traffic Response

The bridge's response to traffic will be determined through static, dynamic, and ambient vibration load tests. CIBrE will work with DelDOT to determine the appropriate tests to conduct and the time of the tests, to coordinate traffic, and to obtain the required loading trucks. Additionally, any instrumentation needed to perform the load tests should be purchased and tested well in advance of the actual tests. Additional instrumentation may include scales, cameras, gauges, and wires. Once all of this information is available, a detailed plan and schedule for the load tests will be developed and available for review. As stated previously all collected data should be stored and made available to DelDOT for future use.

8.4 Wind Response

The bridge's response to wind loading will be determined by gathering bridge response data under ambient wind conditions. Also, CIBrE will measure wind conditions at a weather station located near the bridge (the exact location of the weather station has yet to be determined). It is intended that ambient wind data and response will be taken over a one-year period of time to quantify the baseline behavior of the bridge's response to wind loadings. A site-specific wind history will also be developed for the Indian River Inlet. All collected data should be stored and made available to DelDOT for future use.

8.5 Thermal Response

Seasonal variations in response due to temperature will be tracked, and displacement and internal strains will be monitored. To determine the baseline behavior of the bridge, one year's worth of data will be captured. This data will help to determine the at-rest stresses and strains that were present in the bridge before it was opened to traffic. All collected data should be stored and made available to DelDOT for future use.

CHAPTER 9

STAGE V – LONG-TERM CONDITIONS

9.1 Overview

During Stage V, the bridge will be continuously monitored. CIBrE will actively take part in the monitoring of the bridge up to the first biannual inspection. CIBrE's main goal for this stage of the project is to create a database of monitoring data and reports that will allow DelDOT to effectively monitor the structural health of the bridge throughout its service life. CIBrE also hopes to use the data collected for research purposes.

9.2 Biannual Inspection

During the first biannual inspection of the bridge, CIBrE intends to conduct load test on the bridge. The load tests will be similar to the tests conducted after the completion of the bridge. The test will serve as a measure of long-term performance. Results will be compared to the initial baseline response determined previously. CIBrE will use the results from the biannual inspection, biannual load tests, initial load tests, and the data that have been continually gathered to create a report. That will describe the bridge's current condition and assess the overall effectiveness of the monitoring program. Once the biannual inspection is completed and the report is finalized, CIBrE intends to turn the monitoring program over to DelDOT.

CHAPTER 10

INSTRUMENTATION

10.1 Instrumentation

A variety of gages and sensors will be used in the instrumentation of the Indian River Inlet Bridge. This chapter is intended to identify these gages and sensors and to give important information relating to their purpose, purchase, installation, setup and use.

Upon completion, this chapter should list specific brands and models of sensors to be used, list sources for purchasing the sensors, cite relevant manuals related to the sensors, and give a step-by-step procedure for the installation and set-up of each sensor.

However, at this time this chapter lists only a few highlights about each sensor type. These highlights include how the gage is mounted, what each gage measures, what the measurements will be used for, and some miscellaneous considerations about each sensor.

10.1.1 Foil Strain Gage

- Mounted on sister bars, then embedded in concrete sections
- Measure strains
- Ideal for high frequency reading
- Allow for the determination of plane strain in a section when used in groups of three (four including a backup)

- Will be used primarily to track event data such as load tests and wind events

10.1.2 Vibrating Wire Strain Gage

- Mounted on sister bars then embedded in concrete sections
- Measure strains and temperature
- Ideal for low frequency reading
- Allow for the determination of plane strain in a section when used in groups of three (four including a backup)
- Will be used primarily to track long-term behavior, creep, shrinkage, and thermal effects

10.1.3 Accelerometer

10.1.3.1 Use in Concrete Sections

- Surface mounted using epoxy
- Measure acceleration of a section
- Allow the dynamic behavior of the bridge to be examined
- Will be used to determine the dynamic response of the bridge to wind and traffic

10.1.3.2 Use On Temporary Stays

- Mounted how?
- Measure acceleration of a cable
- Allow the determination of tension in a cable
- Will be used to track temporary stay forces during construction

10.1.4 Global Positioning System (GPS)

- Surface mounted
- Measures change in position of the arch crown and each arch base
- Allow the determination of absolute movements of the arch crown and arch bases
- Will be used to evaluate settlement, thermal effects, and lateral deflection of the arch crown during wind events
- Accuracy on the order of ______

10.1.5 Linear Potentiometer

- Surface mounted
- Measure relative movements at bearing locations
- Allow a time history of bearing movement to be constructed
- Used to evaluate thermal movement and effectiveness of the bearings

10.1.6 Chloride Penetration Sensor

- Embedded in the reinforced concrete pile caps
- Measure the concentration of chloride particles
- Allow a time history of chloride concentrations in the pile cap to be constructed
- Used to evaluate possible corrosion of reinforcing steel

10.1.7 Void Detection Sensor

- Wire sensors embedded for the entire length of a tendon
- Detect voids in grouted tendons

- Capable of differentiating between air voids and water voids
- Allow the mapping (size, location, and type) of voids in grouted tendons
- Used to evaluate the grouting techniques
- Require special holes in anchorages

10.1.8 Anemometer

- Surface mounted on temporary construction towers
- Measure site specific wind data during construction
- Allow site specific wind data to be compiled for the time that the temporary construction towers are in use
- Used to characterize site specific wind characteristics
- Used to document significant wind events during construction

10.1.9 Load Cell

- Measure force in selected support cables
- Custom built to specifications listed below
- Allow a time history of support cable forces to be constructed
- Used to determine bridge behavior under dead and live loads
- Used to track changes in behavior of the bridge as it ages

Table 10.1 Load Cell Specifications

Capacity	5,000,000 lb range
Environmental	Splash proof
Temperature range	-30 to 150 deg F
Non-linearity	1%FS or better
Dynamic reading capability	
Calibration certification required	
Must accommodate pressurized nitrogen system	
Include a pressure gauge with a range from 0 to 10 psig that reads in 0.1 psi or finer increments and is capable of communicating with data collection equipment	

CHAPTER 11

REPORTING OF DATA

11.1 Reporting of Data

The Indian River Inlet Bridge Monitoring Program involves installing many gages and sensors on and in the bridge to collect data. However, the raw data itself will be of little use until it is processed and interpreted. The results of the processing and interpretation must then be put into report form so that the information may be conveyed to interested parties to allow the goals of the instrumentation program to be met. This chapter includes the following for each stage of the project: the purpose of the reports, what should be included in these reports, when they should be issued, and what parties may be interested in the information contained in the reports.

11.1.1 Construction Stage

During the construction stage, the main purpose of collecting and analyzing data will be to

- Record the evolution of stresses, forces, and moments in members instrumented with strain gages
- Record the evolution of forces in support cables and temporary stays instrumented with load cells or accelerometers

- Record the evolution of settlements, relative movements, and displacements for members instrumented with linear potentiometers and GPS units
- Gather site-specific wind data from anemometers on the temporary towers

During this phase bimonthly reports will be issued by the University of Delaware to DelDOT. Information contained in these reports will include maximum and minimum values for each gage during the report period, as well as maximum and minimum forces, moments, displacements, and relative movements for each given member. Any unexpected values or significant discrepancies from predicted values will be discussed.

A final report will be issued at the end of construction. This report will include plots for each member that show the evolution of forces, moments, and displacements throughout the entire construction process. It will also include information on the wind data collected during construction. A discussion of unexpected results and discrepancies from expected values throughout the construction phase will be included.

The information contained in these reports will be of interest to DelDOT, the designer, the independent reviewer, and the contractor. The reports may be issued by DelDOT to these and other interested parties as deemed necessary.

11.1.2 Initial condition Stage

During the initial condition stage, the main goal of data collection and analysis will be to establish the baseline behavior of the bridge. Specific areas of interest include

- Determining the initial state of stress of the bridge under ambient conditions
- Quantifying the behavior of the bridge due to several load tests
- Quantifying the behavior of the bridge due to ambient traffic
- Quantifying the behavior of the bridge to any significant weather events such as high wind or large temperature changes that may occur

A report will be issued by the University of Delaware to DelDOT for each of the above bulleted areas of interest. Each report will contain maximum values for stress, force, moments, displacements, etc, for each member due to each specific event. Records of actual average responses will also be included and compared to predicted responses.

The information contained in these reports will be of interest to DelDOT, the designer, and the independent reviewer. The reports may be issued by DelDOT to these and other interested parties as deemed necessary.

11.1.3 Long-Term Monitoring

The main goals of the long-term monitoring portion of the program are to supplement standard visual inspection of the bridge as well as to determine whether the current behavior of the bridge differs from the baseline behavior. This will be accomplished by repeating load tests on the bridge and comparing current wind, traffic, and temperature events to similar past events.

A report will be issued at the first biannual inspection of the bridge. It will include data similar to the reports from the initial condition stage. However, the discussion of data will compare current values of response to past values of response in addition to values of response predicted by design. Unexpected results will be discussed.

The information contained in these reports will be of interest to DelDOT, the designer, and the independent reviewer. The reports may be issued by DelDOT to these and other interested parties as deemed necessary.

The current contract between the University of Delaware and DelDOT ends after the first biannual inspection. Additional reports at biannual inspections may be handled under separate contracts as the need arises.

APPENDIX A

DEFINITIONS

A

B

BASE STATION – The temporary data logger that will be located at the base of the southern temporary tower that will log data from the instrumentation on the temporary tower and temporary stays during construction

C

CIBrE – Acronym for "Center for Innovative Bridge Engineering"

COMMUNICATION CABLE – Cable that connects a data acquisition system to the UD communications enclosure

COMMUNICATIONS CONDUIT – Conduit that runs from data acquisition systems to the UD communications enclosure for the purpose of housing communication cables

CONDUIT – Pipes installed for the purpose of protecting wires or cables

CONTRACTOR -

D

DATA ACQUISITION SYSTEM – Piece of data acquisition equipment housed in a metal box that gathers data from surrounding gauges through gauge wires then transmits that data to the UD communications enclosure through a communication cable, permanent part of instrumentation program. Locations of data acquisition systems are specified in the bridge electrical plans.

DATA LOGGER – A piece of data acquisition equipment that is connected to gauge(s) by gauge wire and has the ability to communicate with and store data returned by the gauge(s), but does no communicate with the UD communications enclosure. Data loggers will be used to collect data during construction and will be removed upon installation of data acquisition systems.

DelDOT – Acronym for “Delaware Department of Transportation”

E

EMBEDDED GAUGES – Gauges which are encased in concrete (or grout) because they are internal to a segment and concrete has been cast around them

EVENT DATA – Data which is taken at a high frequency to capture effects from live loads such as wind and traffic

F

FIGG -

G

GAUGE – An instrument or means of measuring and/or testing

GAUGE WIRE – Wire which transmits data from a gauge to a data acquisition system or data logger

GPS – Acronym for “Global Positioning System”

H

I

INFORMATION KIOSK -

INSTALLATION EQUIPMENT – Apparatus for installing gauges, data acquisition systems, sister bars, etc. in the bridge, includes but not limited to wire ties, epoxy, bolts and nuts

INSTRUMENTATION PROGRAM - The portion of the monitoring program that is concerned with the purchase, installation, and set up of gauges, gauge wire, communication cable, data loggers, and data acquisition systems

IRIB – Acronym standing for “Indian River Inlet Bridge”

J

K

L

LOCAL CONDUIT - Conduit that runs from gauge locations to data acquisition systems for the purpose of housing gauge wire

M

MONITOR DATA – Data which is taken at a low frequency to capture effects from dead load or temperature

MONITORING PROGRAM – The project being undertaken by the University of Delaware which includes instrumenting the IRIB, collecting the data, interpreting the data, predicting data, and communicating results with concerned parties

N

O

P

PROVIDE ACCESS – Allow the University of Delaware to enter the bridge construction site, the bridge superstructure, temporary construction towers, pile caps, bearings, and fabrication yards for precast members throughout the construction process as detailed in this manual. Providing access means that the contractor will provide the means for University staff to physically get to the needed locations to install and read all instruments. It is expected that the contractor will provide the needed lifts, ladders, or other devices to allow this to happen. The period of time allotted for the University to access a section shall not overlap with the period of time allotted for access to any other section. During periods of access provided to the University appropriate lighting shall be provided by the contractor.

Q

R

S

SENSOR – Synonym of gauge

SURFACE MOUNTED GAUGES – Gauges which are mounted to the surface of a section by epoxy or other mechanical methods

T

TEMPORARY STAYS - The cables which act to temporarily support the arch rib during construction

THROUGH HOLE – Holes in specified segments that will be used to run gauge wire or install GPS units

U

UD COMMUNICATIONS ENCLOSURE – The enclosure to the west of the southern abutment that will house UD Communication equipment, see sheet 578 “Site Electrical Plan Bridge Electrical Service”

V

W

X

Y

Z

APPENDIX B

UNIVERSITY OF DELAWARE BRIDGE MONITORING PROGRAM SPECIAL PROVISIONS

B.1 Description

This work consists of providing the University of Delaware (University) access to the bridge construction site, the bridge superstructure, and temporary construction towers throughout the construction process. University staff will be installing internal and external gages in the bridge (both on site and at fabrication yards) and on the temporary towers for the purpose of quantifying bridge behavior during construction and after its completion. The University will be responsible for supplying and installing all of the sensors except for the support cable load cells (which will be purchased and installed by the Contractor). The Contractor shall provide University staff with access and means to reach the locations where the sensors will be installed and read at the appropriate construction phases. The Contractor will also be responsible for the movement of bulky equipment to required locations. In addition, the Contractor will be responsible for the proper installation of University of Delaware monitoring through holes shown in the plans, as well as communication conduit which are also shown in the plans. The Contractor will also be responsible for installing wire pulls in the communication and sensor conduits to allow sensor and communication wires to be fished through the conduit to needed locations. Details of the instrumentation program will be provided at a pre-bid meeting. University staff will be independently safety certified and insured at no cost to the Contractor.

B.2 Construction Methods

B.2.1 General Note

University staff shall be notified at least four weeks prior to work on any of the items listed below. The University will provide the Contractor with a contact person at the outset of the project. In the following notes, “provide access” means that the Contractor will provide the means for University staff to physically get to the needed locations to install and read all instruments. It is expected that the Contractor will provide the needed lifts, ladders, or other devices to allow this to happen. The Contractor will also be expected to allow the University to draw power from on-site generators during selected activities.

B.2.2 Temporary Construction Tower

If temporary construction towers are used in the construction of the bridge, the University intends to install five anemometers at various heights on one of the construction towers. This instrumentation will collect wind speed data during construction. The University shall be provided access to the tower to install each of the anemometers (three hours per anemometer). The locations of the anemometers will be provided to the Contractor once the tower design is complete. The University will also instrument selected temporary support cables to monitor cable forces. Once a design of the tower and cables are complete, the University will specify which cables will be monitored and how the instrumentation will be installed. The monitoring will involve a combination of load cells and accelerometers. At locations that accelerometers are used, they may require the University to have access to the support cable each time they are read. This would require lifts or other means to reach the upper cables. It is anticipated that the installation of instrumentation will require two hours per support cable. Wiring to both the anemometers and load cells/accelerometers will need to be run to a base station located at the base of the temporary tower, and the University shall be allowed access to that base station throughout the time that the instrumented towers are in use.

B.2.3 Bearings

Upon completion of the initial installation of the bridge bearings in the arch base, the University staff shall be provided with access to the bearings for a period of eight hours for the purpose if installing displacement instrumentation. As the south arch base is being constructed, a pull wire should be run through the communication conduit to allow the displacement wiring to be run up into the central beam. Once the arch base is complete, the University shall be provided access to pull the displacement wiring through the conduit and connect it to an appropriate data logger. This will require up to 3 hours. The University shall also be provided with access to the bearings for a period of four hours after they are unblocked at the later stages of the construction. The University shall also be provided with six hours of access each to the bearings at the end of each back span (at the abutments) immediately after their installation to install additional displacement instrumentation. If the contractor prefers, a communication conduit can be run down from the arch base bearing location and then underground directly to the University data kiosk. If this is done, a pull wire will need to be placed in the conduit to allow wiring to be pulled from the kiosk to the bearing location.

B.2.4 Internal Gauges

For the purpose of installing internal gages, the University staff shall be provided with four hours of access to each of the following sections S-C1U, S-C1D, S-T10U, S-T10D, S-T22U, S-T22D, S-T36U, TB-T1U, TB-T1D, TB-T19U, TB-T19D, TB-T37U, CENTRAL BEAM STA. 294+15.583, 1S-8, 1S-17, 2S-3U, 2S-3D, 2S-30U, 2S-30D, 2S-57U, 1N-8, 1N-17, 2N-3U, 2N-3D, 2N-30D, 2N-30U, and 2N-57U before each section is cast, but after the rebar cage is complete. Access and a means to reach any location of entire rebar cage at these sections shall be provided by the Contractor. During the installation, the University will be running wiring through the sections to an 8-inch by 8-inch by 6-inch block-out box that will also be installed by the University. Location and installation of the block-out boxes will be selected in consultation with the Contractor to ensure that it will not interfere with the construction methods. During casting of segments, the Contractor will ensure that the gages, wiring, and block-out boxes are not damaged. The University reserves the right to substitute alternative sections for instrumentation if the Delaware Department of Transportation (DelDOT) determines that such alternate sections need to be instrumented.

B.2.5 External Gauges and Data Acquisition Systems

In order to install external gages and attach wires to local data acquisition systems, an additional eight hours of access shall be provided to the interior of each section listed above (in the "Internal Gages" section) directly after it has cured (cast in place) or been placed (pre-cast). Four hours of access to the top and interior of the central beam at Stations 294+78.000 and 305+22.000 must be provided directly after these segments have cured (cast in place) or been placed (pre-cast).

B.2.6 Through-Holes

In order to run wiring for the instrumentation from the northbound and southbound sections into the tie beam and central beam, two-inch diameter through-holes have been specified in the plans for sections: TB-T1D, TB-T1U, TB-T19D, TB-T19U, TB-T37U, CENTRAL BEAM STA. 294+15.583, 1S-8, 2S-3U, 2S-3D, 2S-30U, 2S-30D, 2S-57U, 1N-8, 2N-3U, 2N-3D, 2N-30D, 2N-30U, and 2N-57U. It is the Contractors responsibility to make sure that the through-holes in tie-beams or central beams match up with the through-holes in the adjacent roadway sections (within a tolerance of 1/8 inch), and that the hole is clear (nominal 2 inch diameter opening) after the closure pour. The following table shows the tie beam/central beam sections and the adjacent roadway sections.

Table B.1 Though-Hole Sections

Tie-Beam Section/Central Beam Station	Adjacent Roadway Sections	
TB-T1D	NB	2N-3U
	SB	2S-3U
TB-T19D	NB	2N-30D
	SB	2S-30D
TB-T37U	NB	2N-57U
	SB	2S-57U
TB-T19U	NB	2N-30U
	SB	2S-30U
TB-T1U	NB	2N-3D
	SB	2S-3D
STA	NB	1N-8
	SB	1S-8

B.2.7 Load Cells

University staff will provide the Contractor with specifications for the load cells that will be installed at five arch anchorages and a list of potential suppliers. It will be the Contractors responsibility to purchase and install the load cells. The load cells are cylindrical donuts that will extend the anchorage zone upwards approximately 36 inches. Each load cell weighs several hundred pounds. The load cell assembly should also include instrumentation to allow the pressure sensing for the nitrogen gas system being used in the hanger cables. The cables to be monitored with the load cells are in sections S-A9U, S-A9D, S-A21U, S-A21D, S-A33U. These sections have been selected to avoid sections where temporary support cables are located. The University reserves the right to substitute alternative sections for installation of load cells if the location of temporary support cables change, or if the DelDOT determines that such alternate sections need to be instrumented. The Contractor will be responsible for getting the load cells from the ground to the appropriate locations as specified by the University, and installing both the load cells and nitrogen pressure sensors. Once installed, the University will need access to the load cell and adjacent instrumented sections to connect the load cell to the data acquisition system. This is anticipated to take four hours.

The required specifications for the load cells are as follows:

Capacity : 5,000,000 lb range

Environmental : Splash proof

Temperature range : -30 to 150 deg F

Non-linearity : 1%FS or better

Dynamic reading capability

Calibration certification required

Two potential suppliers are:

CTL Group

5400 Old Orchard Road

Skokie, IL 60077-1030

www.CTLGroup.com

Honeywell Sensotec

2080 Arlingate Lane

Columbus, Ohio, 43228

www.sensotec.com

B.2.8 Hardwire Connections

After external gages are placed at the sections listed below, an additional eight hours of access shall be provided to run instrumentation wire from that section to the closest data acquisition system installed (this is expected to occur right after the gages are installed):

- Upon completion of external gage installation at S-T10U, access shall be provided through the center of the arch from section S-C1U to S-T10U
- Upon completion of external gage installation at S-T10D, access shall be provided through the center of the arch from section S-C1D to S-T10D

•Upon completion of external gage installation at S-T22U, access shall be provided through the center of the arch from section S-T10U to S-T22U

•Upon completion of external gage installation at S-T22D, access shall be provided through the center of the arch from section S-T10D to S-T22D.

B.2.9 Data Collection

During bridge construction, the University staff will require periodic access to the all data acquisition systems installed in the arch and tie-beam segments in order to download data. It is anticipated that data will be retrieved from all installed data acquisition systems on a weekly basis. It will take no more than one hour per location to download data.

B.2.10 Corrosion Monitoring System

To monitor for future corrosion, instrumentation will be installed into both the arch base support cap and several post-tensioning tendons. The University will install four Corrosion Penetration Monitoring Probe (CPMP) units, one at each corner, of the south arch base cap beam prior to casting. The units will be tied off to the top mat of reinforcing. Monitoring instrumentation will also be installed in selected tendons of both the tie beam and roadway sections. Three post-tensioning tendons in the tie beam (at one section) and six post-tensioning tendons in the roadway sections (three in each of two sections) will be identified for monitoring at the outset of the construction. This instrumentation involves pulling a thin monitoring wire through the ducts along with the post-tensioning strands. The wire will require a separate access hole in the anchorage end plate. To demonstrate the installation of the tendon corrosion system, and to provide calibration, the same system will be installed in the clear ducts used to demonstrate the grouting technique.

B.3 Basic of Payment

The cost of providing the University access for the purpose of installing monitoring equipment, as well as any labor, equipment, tools, etc. will be paid for in a lump sum.

APPENDIX C

UNIVERSITY OF DELAWARE ROADWAY MONITORING PROGRAM SPECIAL PROVISIONS

C.1 Description

This work consists of providing the University of Delaware (University) access to specific portions of the roadway abutment throughout the construction process. University staff will be installing strain gages on specific reinforcement panels for the purpose of monitoring the performance of an MSE wall both during construction and after its completion. The University will be responsible for supplying all sensors. The Contractor shall coordinate transfer of specified instrumented panels from the University, and provide University staff with access and means to reach the locations where the panels will be installed at the appropriate construction phase, as well as to provide access to read data from the sensors throughout the project. Details of the instrumentation program will be provided at a pre-bid meeting. University staff will be independently safety certified and insured at no cost to the Contractor.

C.2 Construction Methods

C.2.1 General Note

The Contractor should notify the PI about the planned installation of the specified panels at least 3 months in advance. The University will provide the Contractor with a contact person at the outset of the project. In the following notes, “provide access” means that the Contractor will provide means for the University staff to physically get to the needed locations to install and later read all instruments. It is expected that the Contractor will provide the needed lifts, ladders, or other devices to allow this to happen. The Contractor will also be expected to allow the University to draw power from on-site generators during selected activities, as well as provide lighting if work needs to be conducted during night time hours.

C.3 MSE Wall Instrumentation

C.3.1 Location

The MSE wall being instrumented is very high and its anticipated settlement is most significant on South Bound SR1 (SB) between Station +292.00 and Station +293+00 (South Abutment). To avoid the effects of the abutment and yet obtain significant data, the desired section location for instrumentation would be 100 feet south of the South Abutment, on the SB side (this location coincides with the location for which MACTEC has specified other instruments to be placed).

C.3.2 Strain Gauge Installation and Reading

Strain gages will be attached to every 4th layer of reinforcement at a spacing of 5 feet apart so as to obtain the strain distribution along that layer starting near its front end. Since geosynthetic material is likely to be used, attachment of strain gages for long-term field performance is not well established yet. Hence, this will be done at the University with the help of an experienced technician. The Contractor should notify the PI about the planned installation at least 3 months in advance of the start of work, and at that time provide the University with details of the exact type of reinforcement being used. The University will acquire and instrument the needed layers of reinforcement. The University will contact the Contractor when the instrumented geosynthetic panels are done (at least 2 weeks prior to being needed for construction), and the Contractor will arrange for them to be taken back to the site for installation. The University will work with the Contractor to make sure that the panels are transported and stored in a manner so as to protect the gages. The Contractor shall provide access to the University at the construction site when each strain gaged panel is placed. The Contractor shall follow instructions provided by the University representative to ensure proper placement of each strain gaged panel. Fill over each strain gaged panel will be placed with care to prevent damaging the strain gages. The University will assist in protecting the gages. Electrical wires connected to the gages will be placed on top of each respective gaged reinforcement layer in a zigzag fashion extending through the face of the wall, and then these wires will be run down the face of the wall to a central box (provided by the University, footprint is approximately 2-feet by 2-feet). The central reading box will be located at least 10 feet away from the wall at the toe grade elevation. The Contractor and University will discuss and agree upon the ultimate location of the central box. The University will fabricate the reading box ensuring it is safe against unauthorized access as well as protected against the environmental degradation. The box will be installed by the University considering possible concerns by the contractor. The Contractor will be provided with instructions as to how to channel all electrical wires to the central box in a 2 foot deep trench (to protect the wires from construction equipment). The trench will be dug in a zigzag fashion to allow for excess wire thus allowing settlement and deformation without stressing the wires. For each strain gaged panel, all wires will be routed down the face of the wall, through the trench, and to the central box. In order to run the wires down the wall face, a ladder or lift will need to be provided by the Contractor. After placement of all wires in the trench, it will be covered allowing for the normal use over the trench. The wires provided by the University will be shielded and water resistant thus needing no special protection after being embedded in the trench. Reading of data will be performed by the University. The Contractor will provide access to the data acquisition system throughout the project to allow data to be collected.

C.4 Basic of Payment

The cost of providing the University access for the purpose of installing monitoring equipment, as well as any labor, equipment, tools, etc. will be paid for in a lump sum.

APPENDIX D

SELECTED INDIAN RIVER INLET BRIDGE PLANS

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B-7
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